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RESEARCH AND DEVELOPMENT IN METALLURGY.*

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The subject chosen for this evening is not inappropriate for presentation to the Franklin Institute, which has for generations fostered researches and presented to the world much new and useful information in metallurgy. In this work the Institute has followed the example of its illustrious progenitor, since Dr. Franklin himself was interested in metallurgy, both as inventor and producer. He seems early to have had a taste for metallurgical lore; among his books was numbered a French publication entitled: "The Art of Converting Forged Iron to Steel, and the Art of Softening Cast Iron and the Art of Making Cast Iron as Finished (elegant) as Forged Iron," published in Paris in 1722. His contribution to domestic progress, through the perfection of the "Franklin Stove" was alone enough to invest him with enduring fame; the stove was perfected in 1742, and described in a pamphlet printed and sold by Franklin in 1744. It is recorded that the first Franklin stoves (seven in number) were cast at Redding Furnace in French Creek, Chester County, Pennsylvania, September 23, 1742. He was also

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the manager of a well-known charcoal iron blast furnace at Warwick, Chester County, Pennsylvania. Members of the Institute have perpetuated this aspect of the Franklin tradition through the Institute's history. To select a single name, John Birkinbine, one of its presidents, was conspicuously identified with the mining and metallurgical professions for many years.

In considering research and development in metallurgy, I would define the former as the systematic investigation of problems relating to metals and their alloys, while the latter embraces the commercialization of the results of the advances attained through the efforts of the former; actually, the two merge to some extent. In the brief survey herein attempted, the commercial aspects will be chiefly stressed, and the discussion based on the conditions in the United States; some of the work done here has been the result of programs started abroad or has been grafted onto them—however, the argument is not affected by that fact.

The qualities of metals and their alloys about which information is most frequently sought, are: tensile strength, ductility, hardness, resilience, electrical properties, and behavior toward corroding media. Lack of time this evening will prevent more than a passing reference to the historical aspect. Metallurgical research as exemplified today in America, is not of recent origin. While blast furnaces and steel plants were equipped with chemical laboratories at an early date, the work done was mostly for the purpose of control of raw materials and products. On the other hand, mechanical testing on a large scale has been practiced since the earliest days of its development. The first tensile tests were being discussed in Europe and England as far back as the early 40's of the last century. Apparently, the first estimates of tensile strength were made by transverse tests. Fairbairn made a series of transverse tests between 1837 and 1841.[1] A rather high type of tensile testing machine was described by T. E. Vickers in a paper [2] in 1861, but it would seem that the most advanced type of testing equipment then extant was manufactured here in Philadelphia, because tests performed at Woolwich Arsenal in England, in 1858, were made on the machine constructed for the United States Army Ordnance Department.[3] Some of

the earlier engineering structures still in use were put up only after careful tensile tests had demonstrated that the steels met the design requirements; examples exist in the Eads Bridge (1873) and others; but as late as 1882 [4] there still lacked a feeling of confidence in the use of steel for structures! "Tests of Metals," an Army publication, dates from 1881, and bears witness to the recognition of the need of accurate knowledge of the strength of materials for control of quality; this annual reports current work performed by authority of an Act of Congress, June 20, 1878, which was the outcome of a demand of the engineers [5] for reliable information on the strengths of materials of construction. The data obtained by the coördination of the chemical balance and the testing testing machine were responsible for much progress after 1875.

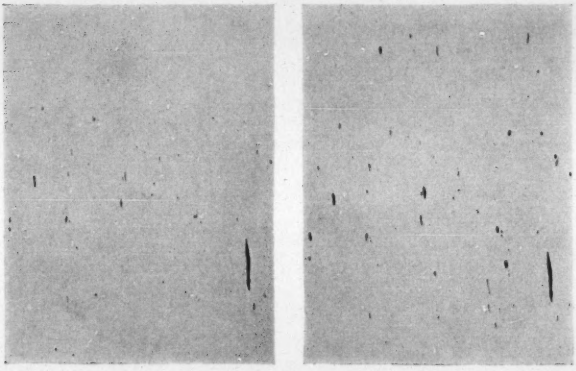
Among other methods of testing found useful today is that known as "fatigue." This had been well established about seventy years ago by Wöhler while he was acting as a railroad official in Prussia, and may be described as an alternate stress and stress relief applied to a section of the metal in such a manner as to produce definite stress values. It is interesting to note the strangely prophetic words which appeared in *Engineering*, 1867, in describing Wöhler's exhibit at the Paris Exposition of that date.[6] "Mr. Wöhler's modest exhibition may have been overlooked by ninety nine out of every hundred visitors to the Exhibition, yet we believe outselves justified in saying that his scientific and patient experiments will be referred to long after the majority of those things which have drawn a shower of medals and ribbons upon themselves at present will be dismissed and forgotten." Drop tests—the forerunner of the present method of proving rails, also used in Germany prior to 1871—have useful modern modifications about which more will be said later on.

The importance of the use of the microscope, described by Sarbey and used so effectively by Osmond and Roberts-Austen, was early recognized by Howe and Sauveur [7] as an aid to metallurgical progress, and both pioneered as missionaries in spreading knowledge of the nature of the physico-chemical changes brought about by the use of heat treatment and alloying elements in iron and steel. For many years the

metallurgical microscope was considered almost as a luxury to be afforded by a few of the largest or most progressive steel companies or institutions of learning, whereas today even a junk yard may consider such equipment a necessity!

In the early 70's, the tensile tests of metals at higher than room temperature were started, and your own Institute [8] disseminated information to engineers in this country through the first translation into English, of certain French experi-

FIG. 1.



a *b*

Illustrates the importance of the proper polishing technique on retaining the inclusions in polishing a steel for metallographic examination. (*a*) Steel properly polished, showing the small manganese sulphide inclusions of a grayish color, and to the right a long black streak of silicates. (*b*) The same field polished on the wrong type of cloth, showing most of the sulphide inclusions dragged out, thus destroying the evidence sought.

ments; this was done by Lieutenant Benjamin Isherwood (later Admiral and Chief Engineer of the United States Navy). Watertown Arsenal [9] published exhaustive data in this field as early as 1890.

The National Tube Company, among the first to undertake such experimentation in this country, was well equipped for high temperature tensile testing as early as 1907. As we shall presently see, this type of experimentation has taken on unforeseen importance. Fatigue testing was under way be-

fore 1920, and commercial X-ray studies on steels were being carried on through the Electro Metallurgical Company laboratory at Niagara Falls during 1919. With the advance of physical science and the increasing demands of industry for more accurate and difficult investigations, metallurgical workrooms have lost the atmosphere of the machine shop, and have taken on that of the laboratory of highest scientific precision.

It must not be supposed that the accomplishments of early workers were of trifling importance, since quite the contrary is true. In ferrous metallurgy alone, the practical and theoretical labors of Cort (puddling and rolling of iron), Huntsman (blister steel), Percy (theory of blast furnace), Kelly and Bessemer (refining of iron to make steel), Siemens (open hearth), Holley (engineering application of steel), Sarbey (metallography), Whitwell (hot blast stoves), Jones (contributions to large scale production), Mushet (alloy tool steels), Howe (theory), Hadfield (alloy steels), Osmond (metallography), Le Chatelier (physical chemistry of steel making), and others, to name but a few, compel even greater admiration because of the results often accomplished with primitive equipment and lack of much fundamental knowledge that now constitutes a working background for those engaged in discoveries in these fields. When one steps out of the field of ferrous metallurgy, Hall (commercial production of aluminum), R. H. Richards (concentration), J. W. Richards (metallurgical theory), Hunt (treatment of ores), Peters (copper), Douglass (copper), Hoffman (lead), and many other names readily come to mind. If it is wondered why more American names did not appear among the pioneers in metallurgy, it must be remembered that for generations Great Britain led in iron and steel production. During the expansion of our metallurgical industry, American genius was directed toward problems of production, and men free for research and invention were busy in other fields, notably electricity. We, in this country, have no reason to feel ashamed of the place we have filled, however, either from the practical or the theoretical viewpoint. In the ferrous field, it may be noted that Mathews when he added vanadium to high speed cutting steels made the greatest contribution to high speed

steel development since Taylor and White demonstrated its possibilities. The explanation of the mechanism of "age hardening" by Merica [10]—the brilliant generalizations of Jeffries [11]—the production of low carbon ferro-alloys of high purity by Becket [12]—will, as time goes on, be written down with other accomplishments in metallurgy as outstanding achievements.

The purpose of metallurgical research and development is at least threefold, namely:

(*a*) To cheapen or otherwise improve the processes for obtaining metals from their natural state or to discover new processes. In this is included intermediate stages of refining.

(*b*) To obtain metals or their combinations that will serve in applications or new needs of industry in which existing materials are partly or wholly inacceptable, and to improve the qualities of metals and their alloys.

(*c*) To multiply the uses to which the present products can be legitimately applied.

A book might properly be written in discussing examples and accomplishments under each of the above classifications.

Work on the improvement of ores for subsequent metallurgical treatment is well exemplified in the copper metallurgy, where such great savings have resulted from the hydrometallurgy of low grade ores; by acid solution leaching and subsequent precipitation of the copper, low grade ores may be profitably worked, which otherwise would prove uncommercial. In the case of zinc, the advances made in electrolytic production of metal from the ores are illustrative. During the first quarter of this century, it has been possible to profitably work much lower grade ores than formerly because of improvements in concentration, cyaniding,[13] flotation,[14] sintering or nodulizing and other technical advances which are in wide use. In the case of the blast furnace reduction of iron ores, progress is being constantly made through higher fuel efficiency and increased production per unit, while the more theoretical aspects of ferrous metallurgy are being investigated by the Bureau of Mines, Bureau of Standards, and many laboratories. In the case of the open hearth metallurgy of

steel, the work at Pittsburgh under the joint auspices of the Bureau of Mines, the Carnegie Institute and the Steel Industry, has already produced results which have led to discussions tending to clarify some of the more obscure theories of the thermo-chemistry involved, especially the chemical and physical properties of the slag. Much experimentation in recent years has led to the improvement of furnace design, particularly as regards the life of the refractories and the conservation of heat through improved thermal insulation. Less heralded but, if possible, even more far reaching developments have been taking place in the metallurgy of the ferro-alloys. Economies in reduction have so cheapened or improved the quality of product that no small portion of the alloy steel development can be traced to this alone.

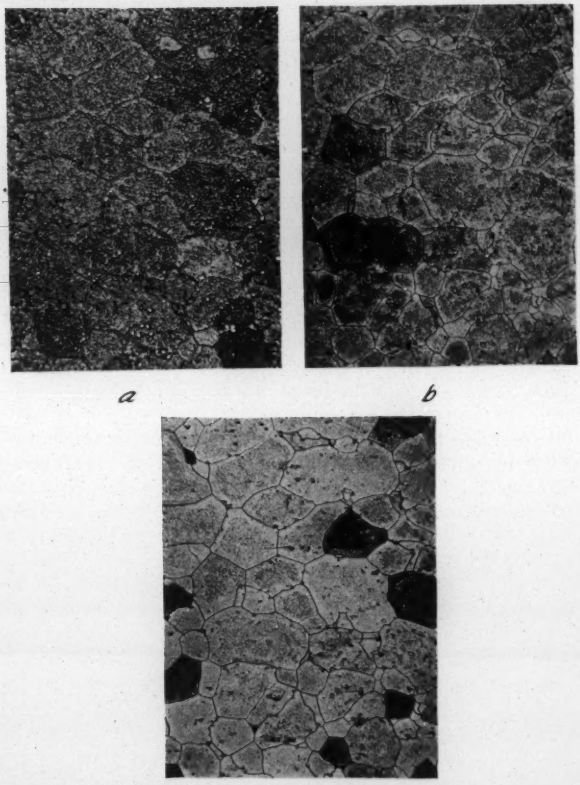
The urge to obtain metals and alloys for new applications has been productive of the most remarkable results, and continues to offer the most attractive outlook for investment of time and effort, since the possible combinations are great in number and the effects often unexpected. Harder [15] has stated the case in the following manner:

"Assuming that we have forty metals which are available for the production of alloys, and we make all the possible combinations of these metals into binary, ternary, and quaternary alloys, i.e., alloys containing two, three, and four metals respectively, we find the possible number of alloy systems which are as follows:

Binary	780
Ternary	9,880
Quaternary	91,390
Total	102,050

"At present about half of the binary alloys have been studied, but most of these have been only incompletely studied. Some 20 to 30 of the ternary systems have been studied. Only one quaternary system, Al-Cu-Si-Mg, has been studied in a comprehensive way. All the other systems are yet to be studied, and research along this line offers great possibilities for future development. It should be realized that we are now using rather many alloys which contain four and five important alloying elements. For example, high speed steel contains iron, carbon, chromium, tungsten, and may contain

FIG. 2.



Illustrating the proper procedure for displaying the true structure of a high chromium steel. (*a*), (*b*), and (*c*) are identical fields, showing (*a*) first polish and etch with disturbed metal remaining. (*b*) light repolish and reetch with removal of some disturbed metal, and (*c*) final polish and etch showing freedom from film of disturbed metal. The process may need to be repeated as much as a dozen times to obtain a true structure of very soft metals.

vanadium, molybdenum, cobalt, and uranium. Dental golds may contain gold, silver, copper, platinum, palladium, and zinc.

"In the above discussion we have mentioned only the number of alloy systems. If we choose to calculate the number of possible alloys and use as the variable a change of 10% in composition, we then get a number of alloys which compares favorably with the total number of chemical compounds which have been so much talked about by organic chemists. The number of alloys become as follows:

Binary alloys	7,020
Ternary alloys	355,680
Quaternary alloys	7,676,760
Total	8,039,460

"This total number of 8,000,000 possible alloys indicates first, relatively how little has been done, and second, what a great unexplored field of metallurgical research we have and what important discoveries are yet in the future." Many obviously unsuitable combinations may be eliminated at once from consideration, such as a zinc base alloy for high temperature service, lead for high tensile service, and other examples, but it is also evident that there remain many possibilities to be explored.

The full fruition of commercial research can hardly be said to have been attained until the maximum number of legitimate uses have been discovered and the product properly applied. Excepting research in pure science—which must be conceded to be the "fountain head"—there must be a well planned and carefully executed effort to exploit the results by the fullest use of the product in every legitimate manner. By reiterated use of the word "legitimate," is meant economic use of the product in the best sense of the word, taking into consideration the ultimate economy of service. Proper exploitation of the fruits of the research affords suitable reward for the expense of the work, and at the same time confers a benefit on the user of the product. Such development work has reached a high state of perfection in recent years, and takes any one of several different forms. Technical articles are a recognized method of announcing the results of research work

to those interested. These articles will inevitably vary in quality—from thinly disguised propaganda of little or no scientific or practical value on the one extreme, to highly important technical or scientific announcements at the other extreme. Periodicals or "house organs" are another type of carrier of information to the public; in these, commercialism is not a taint however, since much useful and eagerly awaited information is frankly put forth with no claim to orginality of research. The technical public is quick to ascertain the difference between the extremes of "bunk" and true technical value. and will goven itself accordingly.

Sales service or sales development is still another method of expanding the use of the products of research work; this may be practiced by the staff experts in the interest of a large corporation. Industry is greatly helped in many cases by a high type of engineering service thus made available. In any case, public discrimination is the final arbiter of service and product, the charlatans falling by the industrial wayside, while real assistance or meritorious products are sustained in public favor. Straightforward advertising of the products of research also has recognized effectiveness and propriety.

The precise enumeration of metallurgical research activities in the United States today is very difficult. This difficulty arises from several causes, such as magnitude of the operations, the fact that in some establishments operations have been more or less curtailed, and partly because some of the work is being done under modest circumstances or is as yet little heralded to the public. In spite of the business conditions today, metallurgical research work is going ahead with no apparent abatement of interest or support. It is true that some retrenchments have been necessary with a need for contracting the schedules on certain programs with less immediate prospect of success or profits; nevertheless, this very condition has resulted in a stimulation of effort in other lines looking toward the days which experience tells us are, let us say, not too far in the future!

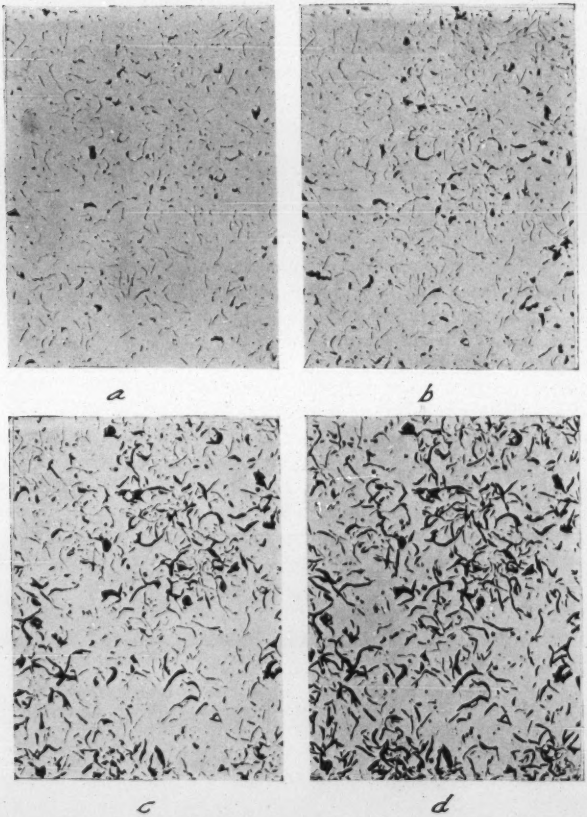
Many of the large metallurgical industries in this country have maintained research and development work for a number of years. More than twenty years ago, it was my good fortune to work for a large and very progressive copper com-

pany, which at one time—to recall a single instance—conducted a plant experiment on which no less than twenty-seven technical graduates were engaged, in addition to the regular plant employees. It may be stated parenthetically that this company did no "window dressing" with its research, but was nevertheless a recognized technical pioneer in its field of metallurgy.

Large metallurgical companies today are supporting their own research organizations in well founded laboratories which represent heavy capital investments. Technical staff organizations or laboratories have also been established by groups of smaller companies which pool their financial support and their problems, thus reaching their objectives with less cost to the individual and eliminating repetition of effort. This works satisfactorily where the problems of group members are similar in character, although the scheme may necessarily cause some slowing up in ability to quickly reach a given problem. In this type of research, coöperative effort may even go as far as mutual sharing of cost investigations. While such a coöperative effort is admittedly for the smaller company, it has been suggested in a sense for the "industrial giants," at least as far as concerns central location; one research executive has confided the dream of a location in a suitably quiet and secluded neighborhood of several of the large industrial research laboratories—a picture something like a university, but with each organization distinct and separate from the others except as regards the common center. Alas for such an enticing prospect, the eggs seem to be scrambled by the fact that many research projects are now scattered over the country and housed in their own elaborate plants.

Into the general picture we must also take the Army and Navy. Researches on X-rays at Watertown Arsenal, corrosion fatigue testing at the Naval Experiment Station, and development work at Wright Field, have all been of the highest type of utilitarian service to the nation at large. When the researches on strictly metallurgical projects at a score [16] or more of universities and colleges, railroads, etc., are added in, the total is seen to be much more than is realized without a careful study. Experimentation of such a general

FIG. 3.



(*a*), (*b*), (*c*), and (*d*) illustrate the effect of too much and the wrong kind of polishing on the structure of gray cast iron. (*a*) proper cloth and polishing procedure to reveal the true structure of the graphite. (*b*), (*c*), and (*d*) are the identical field with successive periods of polishing of 1 min. each. The result has been to drag out the graphite, enlarge the cavities it occupied, and to entirely distort the structure.

character as to merit the support of industry at large is also being done by the research committees of the various national technical societies, and many of these have numerous points of contact with metallurgy. The American Institute of Mining and Metallurgical Engineers has an Institute of Metals Division, and an Iron and Steel Division; The American Society for Steel Treating is devoted to purposes in the metallurgical field much broader than its name indicates. The American Society of Mechanical Engineers, and the American Society for Testing Materials committees touch metallurgy in many fields.

It is a fact that metallurgical work frequently will be done on problems of quite diverse nature, such as those investigated from the aspect of pure science or those in which the objective is to cut costs of operations in the plant. Such diverse requirements naturally lead to many types of organization and forms of administration. In some cases the research department is separate from all others, and is responsible only to a general officer of the company. In other cases, the department may be tied in with production or with sales, or both. Organization, functional activities and relationship of research to industry have been much discussed in recent literature, and those interested may find references in the appended bibliography.[17]

As indicative of the sum being spent at present in this field, an inquiry was directed to a dozen or more large metallurgical research establishments in the United States to secure an estimate of their annual expenditure solely for the improvement of the quality of metals and alloys. It was realized that this would be rather a difficult question to answer because any given research in an industrial laboratory nearly always branches off into collateral lines. However, from the replies received, it is clear that $5,104,000 is accounted for, with no allowance made for the costly experimentation which is going on in the strictly operating departments of the respective plants. While the question was directed toward the laboratory group which would represent the greatest organized expenditure in this line, the returns by no means represent the country as a whole, which I estimate would total at least $12,760,000 annually, including the sum mentioned

above. Counting in the sums for experimentation ged the head of operating departments, the sum is pr n as nearer $20,000,000. p

You may be interested in knowing more about some places in this country where metallurgical laboratory work is being done today. Only a few of the many institutions even be mentioned and then only as typical. While not voted exclusively to research in metallurgy, the Mellon Institute of Industrial Research has done and continues to do much valuable work in this field. The annual reports of this Institute bear witness to the relative importance of metallurgy in its activities. Resources in men and facilities are available to industry on a sponsored fellowship scheme.

A rather unique establishment exists in the Battel Memorial Institute at Columbus, Ohio, which confines its efforts to subjects related to metallurgy, both of a fundamental and practical character. It was endowed by t will of the late Gordon Battelle, and is not owned by any company or interest, and like the Mellon Institute, is able to impartially investigate problems for industry. The Institute has attracted research workers of international reputation, and the equipment is both excellent and varied.

Coming to still another style of set-up, we have the schen in vogue at the University of Michigan where metal industri of the State can obtain the advice and laboratory facilit of members of the staff at Ann Arbor, the school in this ca acting as an industrial laboratory organization to underta work paid for by the client. A somewhat different conditi is found at the University of Illinois, where much sponsor work has been done on a large scale for metallurgical interest especially in the strength of materials. Some of the largest equipment available for strength testing is housed in the Engineering Experiment Station at Urbana.

Among the laboratories owned and operated exclusive in the interest of a single company, we have examples in th new Aluminum Company of America Laboratories at New Kensington, Pennsylvania, the new laboratories of the International Nickel Company at Bayonne, New Je and the central research group of the U. S. Steel C ion at Kearny, New Jersey.

interesting story might be told concerning the specific Society tests of testing which constitute the procedure in the Materials laboratories we are discussing this evening. Some of the more important ones will be touched upon with stress upon their special significance to the development of more useful products. Reference was made earlier to the subject of fatigue testing. At the present time, this test consists of placing upon the test piece alternating stresses of known magnitudes. A common type consists of a rotating beam to which known weights or springs are attached to induce a definite stress in the test piece. Since the early work of Wöhler, this method of testing has been quite extensively adopted, and we have today modifications of the fatigue test, in that the material may be tested at high or low temperatures in order to determine the "life" of the specimen at other than room temperature. Dr. McAdam, for the United States Navy, has specialized in the effect of corrosion on fatigue life,[18] and this type of experiment is being conducted elsewhere at several places. The sample to be tested is stressed under known and controllable conditions, such as to illustrate the effect of water corrosion or other attacking media. Facts which explain the erratic behavior of metals, due to scratches or rust patches, have been brought out in such researches.

It was early recognized that the maximum stress required for rupturing a metal at high temperatures was—within certain limits—inversely related to duration of the stress at any given temperature, a relationship which is nicely illustrated by the data of Wilhelm.[19]

Test No.	Duration of Application of the Load in Minutes.	Load to Cause Rupture Lb. per Sq. In.
1	6	53,500
2	70	44,500
3	240	41,600

The foregoing tests were made at 500° C. (930° F.). It must also be remembered that the drop in maximum stress also is a function of the temperature, so that as the temperature rises, the effect of duration of stress becomes more accented; it should be noted that below certain critical temperatures which are characteristic of the given metal, there is a work-hardening effect which tends to arrest strain in the test piece. This property of slow deformation led engineers to recognize

the need for a study of the behavior of metals under prolonged duration of stress. This elongation has come to be known as "creep," and methods for its detection are called "creep tests." The need for accurate knowledge of this property of metals has risen because of the modern urge to go to higher pressures and temperatures in technical equipment, such as oil cracking stills, boilers, digestors and similar apparatus. It therefore becomes necessary for the mechanical engineer to be supplied with information concerning the so-called

FIG. 4.

Photomicrograph of low carbon steel at 1000 magnifications taken by the conical illumin. method developed by Mr. H. S. George. This illustrates the type of boundaries possible of velopment in the adjacent grains of a metal. The grain at the lower right-hand side has a scratch purposely made with a needle. This grain is a relatively high plateau on the section. It is bounded on the lower left-hand corner by a grain lower in altitude, which in turn is separate from the grain in the upper section by a boundary of the ridge type. The grain at the top of the picture has a pebbled appearance due to the effect of the etching acid.

"creep limits" of the steels used for steam lines, fittings, turbine blades, etc. The creep limit, therefore, becomes a new kind of tensile test critical point, whose relationship to the proportional limit at room temperature is a function of the temperature at which the tests are made. This has been summed up by Archbutt,[20] as follows:

"Below 500° C., creep lies between tensile and proportional limit. At 500° C., creep equals proportional limit, and above 500° C., the creep is below the proportional limit."

Work of the Joint Research Committee of the American Society for Testing Materials and the American Society of Mechanical Engineers along this line is being followed with interest by engineers all over the world. The committee has already found indications that below a given temperature. fatigue is the determining factor in the life of the specimen, while above this temperature, creep is the determining factor.

Shock testing, while one of the earliest forms of proving the toughness of metallic members, has been one of the types recently to be developed and standardized. Falling weights are made to impact the samples under carefully controlled conditions. The time honored drop test still is the ultimate criterion for judging the merit of steel rails.

Among the most spectacular and intriguing tests are the metallographic investigations of metals and their combinations. Improved polishing methods greatly assist the faithful rendering of structural features, and the effectiveness of high magnification metallography has been amplified by the use of ultra-violet light.[21]

The X-ray has been harnessed, and by means of the application of analytical mathematics, atomic structures stand revealed, thus enabling the study and correlation of allotropic phase changes not hitherto possible.[22] Recently, gamma emanations from radium have been put to work, and at a given moment this marvelous element may be working in the hospital for the relief of human suffering, and its bottled emanations at the same time be disclosing defects in a casting.[23]

$20,000,000 is a large sum of money, and it may well be asked what the nation receives in improvements, for its expenditure. Many answers to this question have been given; that the final answer has been favorable to research is attested by the continuation of effort abroad as well as in America. Progress is dependent upon improvement, and steady improvement can result only from knowledge which in turn is best obtained from an orderly study of the events made to take place according to a prearranged schedule. "Granted," you will say, "but these things are all likely to be intangible"; let us look then at some of the tangible results which have

already been placed on the credit side of the ledger, selecting random examples as indicative of past attainments and future prospects.

Sir Robert Hadfield [24] has stated that due to the discovery of 4 per cent. silicon steel of high permeability and low hysteresis, which is used in transformers and other electrical equipment, coal to the value of at least seven million pounds sterling has been saved in the world each year. In such an example, it is comparatively easy to calculate the approximate saving, at least within reasonable limits, and to definitely show the return in dollars and cents. However, there is another class of improvements resulting from research work, that is very large and in which the gains are no less real, but are more difficult to directly estimate. "Permalloy," an alloy with approximately 78 per cent. nickel and 22 per cent. iron, has been developed for use in marine cable communication work.[25] By means of its employment, the ability to transmit messages over the cable has been increased about fourfold. In this single example—probably not susceptible of monetary assessment of savings—human welfare would actually be set back if it were necessary to return to the conditions that formerly existed with respect to the efficiency of communications. Ductile tungsten has been used as an illustration many times, but still remains unhackneyed. When one considers the multitudinous uses of the tough, resilient tungsten wire in those services such as automobile headlights, railroad coaches, or even household uses, the contrast with the former brittle, fragile incandescent lamp filament is sufficiently startling. The money saving in energy from the use of a more efficient filament probably dwarfs that of the case mentioned above.

In the field of light alloys, the progress has been toward new compositions of greater strength and ductility, and amenable to heat treatments. These are not important in the engineering field alone where they are essential in connection with the lightening of structures, particularly in aircraft, but they are of great utility in the form of furniture, and in connection with these metallurgical combinations much work has recently been done to prepare their surfaces to withstand corrosion to which they are likely to be subjected.

Paralleling these advances, the alloy steel art has made great progress. In the category of lower alloy content steels, the betterment in quality, tonnage and diversity of application has been remarkable. The improvements have come along the lines of lowered cost, more acceptable properties, and greater ease in fabrication. In the case of the engineering steels—that is, those used for dynamic rather than static loading—there has been a steady tendency in recent years to lower the carbon content to that of the so-called "mild" steels, and at the same time raise the percentage of alloying elements; in fact, we may be approaching an era of alloy "irons" rather than "steels." Several years' experience has demonstrated the soundness of the principle of obtaining higher mechanical properties without sacrificing the almost universal requirement of toughness; this results from increase in the alloy content and lower carbon compositions.[26] Savings in weight and in first cost are both the result of the use of alloy steels for structures. For example, the use of nickel steel was justified in the East River bridges, and lately by means of medium manganese steel plates and rivets, substantial savings in both the cost of material and fabrication were effected on the Kill van Kull Bridge; in the latter case, the permissible unit stress on rivets was raised from 15,000 lb. per sq. in. for plain carbon steel, to 22,500 lb. per sq. in. for the medium alloy steel.[27]

Undoubtedly, the most spectacular and epoch-making issue in ferrous metallurgy of the past generation has been the advent of corrosion resisting steels. Not only are all engineers familiar with their multifarious uses, but they have also become a household word through their well-nigh universal application to man's needs. One may even go further than this by saying that they have, in fact, practically made possible certain industries. Metallurgical research has proved that the chromium and chromium-nickel steels are resistant to corrosion because of the immunity to attack imparted through the development of surface-protecting oxidized films which, however, may be so thin as to be invisible. This is true in the case of aluminum also, which in very pure form is used for the transportation of certain acids. This property, therefore, makes possible the use of metallic construction for

reaction chambers, digesters and innumerable applications in which the strength, workability, thermal conductivity and general convenience of handling of metals are of indispensable utility. Throughout the whole field of man's activities, these remarkable alloys have been found to increase the usefulness of metal. In the home, the factory, the restaurant, the hospital and in architecture, they are filling a multitude of needs. A whole literature has sprung up on the subject of stainless steels and their uses, and it would be possible to give innumerable references to the large savings made through their use. The life of mine pumps in acid waters has been increased many times, and chromium steel cables in submarines have been in use for four years without showing deterioration, whereas galvanized steel rope has shown deterioration usually in nine months.[28] Improvements like these, —resulting in greater convenience and large monetary savings, —when integrated throughout industry will be found to amply justify the efforts being made for progress through research.

Great strides forward have been taken in the field of harder metals. These have been notable in the case of cutting tools, for example those of Stellite and tungsten-carbide. The armoring of surfaces by means of autogenous welding to resist wear through the deposit of hard alloys or steels is also bringing great savings to industry. This naturally introduces the subject of welding—both gas and electric—and here again great strides have been made, almost in recent months. Pipe lines have been pushed across the continent at a fraction of the cost for the joints formerly necessary when fittings were used —all made possible by the advances in welding technique resulting from researches looking toward the improvement of welding rods and their manipulation. Surface hardening by nitrogen is also of recognized commercial importance because of the greater resistance to wear and substantial increase in the corrosion resistance of the nitrided part, together with less distortion in heat treatment.

Looking at the credit side of the ledger, one is immediately aware of an "embarrassment of riches" rather than a futile attempt to justify this great work of the metallurgists. In fact, did time permit, one could easily expand the barest mention found herein to a list of many, many advantages

which we enjoy because of metallurgical research, any one of which the public would not sacrifice for the relatively trifling sum it has cost us in dollars.

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AMPLIFIERS FOR PRECISE OSCILLOGRAPHIC MEASUREMENTS.

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INTRODUCTION.

The modern electromagnetic oscillograph is remarkably flexible in its operation, recording quite distinctly phenomena occurring in as short a period as 1/10,000 of a second, as well as those persisting for as long a period as several minutes. There is one limitation to the usefulness of the instrument within this frequency range and that arises from a characteristic inherent in all types of galvanometers. In general, as the current sensitivity of galvanometers increases, they become more sluggish in their operation. As applied to oscillograph vibrators, this means that the current sensitivity of a vibrator must be sacrificed, at least in part, if its response to the higher frequencies is to be good. This is illustrated in Table I, which gives the nominal ratings of three typical styles of vibrators made by a prominent manufacturer.

TABLE I

Comparison of Oscillograph Vibrators.

Type.	Sensitivity in Amperes per MM. Deflection.	Natural Frequency of Vibration in Cycles per Sec.
1	500×10^{-8}	5000
2	24×10^{-8}	3000
3	8×10^{-8}	1300

The high natural frequency of vibration of the first type listed, which is known as a standard vibrator, is indicative of its high quality of reproduction and frequency response. Because of this, it is the most desirable of all the types for precise oscillographic work, even though it has the poorest current sensitivity.

Consideration of these factors gives definition to the problem involved in the design and construction of amplifiers for the most accurate oscillographic service. Any amplifier

in this classification must amplify equally all frequencies within the operating range of the oscillograph vibrator, including continuous currents, and at the same time yield sufficient gain to give the desired overall voltage or current sensitivity. Further, such an amplifier must have a relatively high current output, of the order of 250 milliamperes at a quarter of a volt. Lastly, an amplifier to be used with an oscillograph must possess steadiness quite beyond that required in other types, as an oscillographic record might easily be spoiled by a slight unsteadiness for a small fraction of a second, which would pass entirely unnoticed in a speech amplifier or similar device. This requirement for great steadiness is the principal cause of the difficulties to be overcome in designing and constructing amplifiers for precise oscillographic measurements.

THE OUTPUT STAGE.

The specification that the amplifier be effective with continuous currents as well as alternating at once limits the amplifier circuit to the pure resistance coupled type. Also, experience has shown that this is the only type of circuit that will give reproduction of the high quality requisite for precise measurements.[1] The output stage must be decided upon before the voltage amplification stages can be designed. It is the function of these stages preceding the output to amplify the voltages to be measured to sufficient magnitude to operate the high current output stage.

As the voltage across an oscillograph vibrator does not exceed about a quarter of a volt, high plate voltages on the output tubes imply inefficient use of equipment and energy. For reasonably efficient operation, tubes of low internal impedance and operating with low plate voltages are needed. Western Electric 104–D vacuum tubes seem to be the best for this service, yielding a change in plate current of approximately 40 milliamperes when their grid voltage is changed from − 40 to − 10 volts, with a plate voltage of 140 volts and no external plate impedance. When operating in this manner, the tubes are overloaded beyond their nominal rating, but it is so conservative that they behave satisfactorily and have a

[1] S. K. Waldorf, *Trans. A. I. E. E.*, Vol. 47, 1928, p. 1418.

long life. By using six of these tubes in parallel as an output stage, sufficient output current is obtained for the proper operation of a standard vibrator.

THE VOLTAGE AMPLIFICATION STAGES.

The output stage then fixes the voltage change at about 30 volts which the voltage amplification stages must apply to the grids of the output tubes when the input grid voltage change attains its maximum value in any given measurement. The value of the required voltage amplification can be expressed as the ratio:

$$\frac{\text{Voltage change required on grids of output tubes}}{\text{Voltage change available at grid of input tube}}.$$

It has not been found practicable to have this ratio greater than 400, although it is not unreasonable to suppose it could be increased to 8,000 under very favorable operating conditions. As will be seen later, this means that at present the sensitivity of the most precise form of amplifier-oscillograph seems to be limited to about 160×10^{-5} volts per mm. deflection in ordinary circumstances, and to about 8×10^{-5} volts per mm. deflection under the best conditions obtainable.

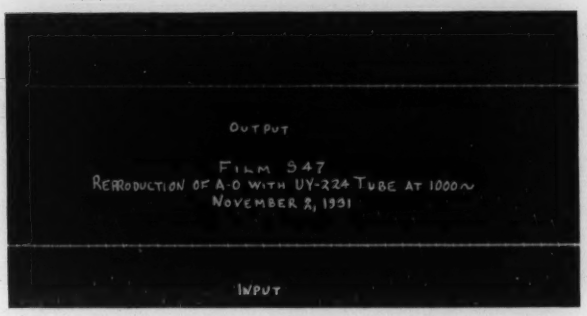
LIMITATIONS OF FOUR ELEMENT TUBES.

To obtain high gain in a resistance coupled amplifier without an undue number of stages, it is desirable that the vacuum tubes used have a high amplification factor. Four electrode tubes used in the screen grid connection fulfill this condition of high amplification admirably,[2] but extensive tests have shown that there are other characteristics which preclude their use. Briefly stated, they have been found to be hypersensitive to conditions of cathode heating, which makes for unsteadiness, and due to the high values of resistance which must be utilized in their plate circuits, their frequency reproduction is poor. For measurements not requiring high quality reproduction, an amplifier has been used

[2] A. V. Eastman, "The Four Element Tube as an Audio Amplifier," Bulletin No. 53, Engineering Experiment Station, University of Washington, Seattle.

successfully which employed a single screen grid stage for operating the output stage. A UX–224 tube was used with its a.c. heater type of cathode supplied from a storage battery. This tube yielded a voltage amplification of 110 with a plate voltage of 180, a screen voltage of 22 1/2, and an external plate impedance of 0.6 megohm. The average overall sensitivity of the amplifier-oscillograph under these circumstances was 8 millivolts per mm. deflection. Figure 1 shows how this amplifier suppressed the higher frequencies and did not reproduce properly an irregularly shaped wave form. Several

FIG. 1.



attempts were made to add a second stage to the circuit but the resulting unsteadiness was so bad as to be prohibitive. By investigating a number of tubes of this type, the source of the difficulty was traced definitely to a slight unsteadiness in the heater circuit inside the tubes themselves.

Experiments with the space charge grid connection of four element tubes indicated that circuits of that type were no more satisfactory than the screen grid type of circuit, so further work on four electrode tubes was discontinued.

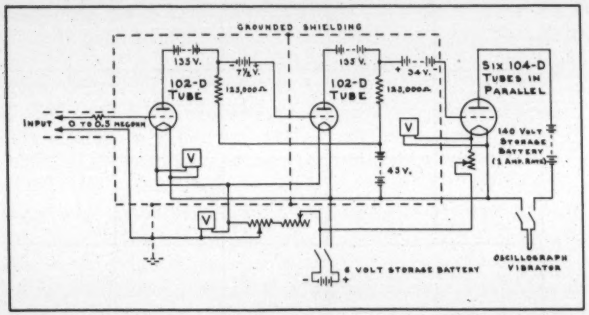
THE UTILIZATION OF HIGH MU TUBES.

The tubes which have proved to be satisfactory both as to steadiness and frequency requirements are the Western Electric 102–D tubes, which are of the three-element high mu

type having a nominal amplification factor of 30. With 125,000 ohms in the plate circuit and a 180-volt plate battery, these tubes give a voltage amplification per stage approximating 20.

In Figure 2 is given the diagram of connections of an amplifier having two voltage amplification stages of the type just described. This circuit has been used extensively for a number of investigations, some of which are briefly described later. Figure 3 gives the calibration of the amplifier-oscillograph when using this circuit.

FIG. 2.

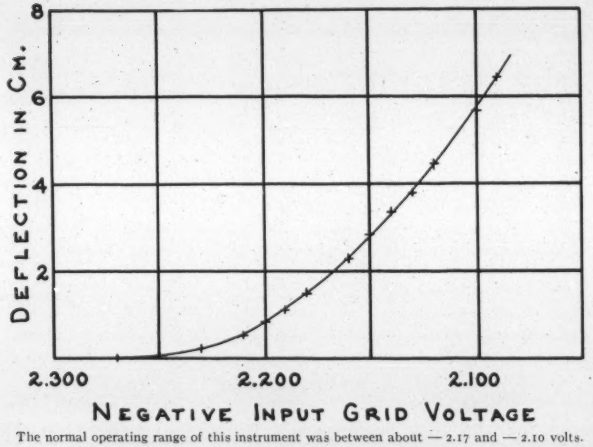


A number of special precautions had to be taken to ensure perfect steadiness and reliability of the instrument. The usual vacuum tube sockets were eliminated and the leads were directly and firmly connected to the prongs of the tubes. Other connections were either soldered to, or secured firmly with, screw connectors. The filament rheostats were especially constructed in the form of a number of fixed resistors with screw connectors for ready adjustment, and a single strand slide wire. To obtain positive contact with the variable slide, and yet be readily adjustable, a binding post type of slide was used. The grid bias on the first tube could be adjusted to within a millivolt with a potentiometer of this same construction connected in the filament circuit as shown in Fig. 2. The bias voltages on the other tubes were adjusted

no closer than allowed by the one and one-half volt taps on their respective bias batteries. This scheme was adopted to eliminate uncertain contacts on additional potentiometers.

On the first two stages, the filament voltage was adjusted to 2.100 volts to within a millivolt. The adjustment on the output stage was not so critical, but these filaments had to draw an unvarying current so as not to cause fluctuations of filament voltage on the 102–D tubes. To minimize any fluctuations which might arise, all filament leads were of

FIG. 3.



The normal operating range of this instrument was between about — 2.17 and — 2.10 volts.

No. 12 B. & S. gauge copper wire. It was found permissible to use vacuum tube sockets in the output stage and not secure the circuit leads directly to the tube prongs.

Until recently, no satisfactory, inexpensive type of plate resistor was available. Lately, reliable wire wound resistors have made their appearance on the market at a nominal cost. In the circuit of Fig. 2, the plate resistors of 125,000 ohms were of this type and fully served their purpose. The value of this resistor was fixed upon to give the maximum voltage amplification without the introduction of frequency distortion.

ADJUSTMENT OF THE AMPLIFIER.

Adjustment of the steady output current to its proper value was accomplished by the following procedure which does not involve the use of instruments other than those used permanently in the circuit. With only the output stage connected, the bias on these tubes was adjusted to that negative value which gave the maximum oscillograph deflection for which the instrument was to be used. This adjustment ensured that the output tubes would yield the maximum required current without their grids having a positive potential. The next preceding stage was then connected to the circuit with a negative grid bias of approximately two and a half volts, which was as much negative as this grid could go on the straight portion of the tube characteristic. The bias voltage on the output stage was then readjusted to bring the oscillograph deflection as nearly as possible to its original value. Following this, the input stage was connected with a negative grid voltage of about two volts, and the bias on the second 102–D stage readjusted to bring the oscillograph deflection as nearly as possible back to its original position. Final adjustment was accomplished with the potentiometer of the input tube. In addition to having the advantage of simplicity, this procedure ensured that none of the grids of the vacuum tubes could have a positive potential as long as the oscillograph deflection was held within the normal working range.

Figure 3 shows the calibration of the amplifier-oscillograph to be slightly non-linear. This characteristic was not particularly objectionable in the studies for which the instrument was intended and so it was permitted to remain rather than introduce further circuit complications.

A linear characteristic can usually be attained by the use of non-linear voltage amplification stages, which are adjusted to compensate for the curved characteristic of the output stage. This method was used in an amplifier described a few years ago by the author.[1]

An alternative is to make the characteristic of the output stage linear as well as that of the voltage amplification stages. To accomplish this, more than six tubes would be required in the output stage, and the useless steady plate current of the

curved portion of the output characteristic would overload the oscillograph vibrator unless compensation were provided.

COMPENSATING FOR THE STEADY OUTPUT PLATE CURRENT.

In ordinary circumstances where it is desired to compensate for the steady component of the output plate current, there are a number of methods available.[3] In oscillographic work, where the currents are relatively large for which compensation must be made, there is one class of circuits which is to be preferred. This class involves the use of an auxiliary battery and connected resistances shunted across the vibrator in such a way as to oppose the flow of the steady plate current. The net effect of the joint action of the compensating circuit and the steady plate current is to prevent the flow of current through the vibrator except at such times as an e.m.f. is applied to the amplifier input.

In Fig. 4 are given four typical circuits of this class, each with the equation of the vibrator current I_G in terms of the circuit constants and the plate current I_p. The equations were arrived at through the application of Kirchhoff's laws. Any one of these circuits may be connected across the vibrator without further modifying the amplifier circuit in any way.

It will be noted that there is a similarity in form of all the equations. In each case the current through the vibrator I_G is a definite proportion of the total plate current I_p, minus a constant quantity. The coefficient of I_p may be called the sensitivity constant, as it is the quantity which determines the proportion of the plate current which passes through the vibrator in excess of a fixed constant value. The constant cannot become greater than unity, for the denominator is the same as the numerator except for an added term.

For minimum impairment of sensitivity of the vibrator due to compensation, the coefficient of I_p should approach unity as closely as possible. This can be done by making the resistances represented in the added terms of the denominator, but not appearing in the numerator, as small as possible in relation to the others appearing in the sensitivity constant. How this can be accomplished practically can

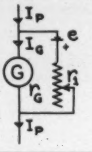
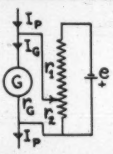
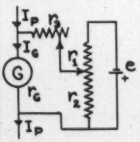
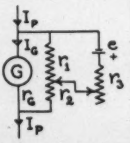
[3] W. B. Nottingham, JOURNAL FRANKLIN INSTITUTE, Vol. 209, No. 3, March, 1930, p. 287.

perhaps best be illustrated by a detailed consideration of the simple conditions of Case I.

In this case the sensitivity constant is

$$\frac{r_1}{r_1 + r_G}.$$

FIG. 4.

CASE	CIRCUIT	EQUATION
I		$I_G = I_p \frac{r_1}{r_1 + r_G} - \frac{e}{r_1 + r_G}$ (1)
II		$I_G = I_p \frac{r_1 r_2}{r_1 r_2 + r_G(r_1 + r_2)} - \frac{e r_2}{r_1 r_2 + r_G(r_1 + r_2)}$ (2)
III		$I_G = I_p \frac{r_1 r_2 + r_3(r_1 + r_2)}{r_1 r_2 + r_3(r_1 + r_2) + r_G(r_1 + r_2)} - \frac{e r_2}{r_1 r_2 + r_3(r_1 + r_2) + r_G(r_1 + r_2)}$ (3)
IV		$I_G = I_p \frac{r_1 r_2 + r_3(r_1 + r_2)}{r_1 r_2 + r_3(r_1 + r_2) + r_G(r_1 + r_2)} - \frac{e r_1}{r_1 r_2 + r_3(r_1 + r_2) + r_G(r_1 + r_2)}$ (4)

Summary of compensation methods.

In general, the minimum value of r_G is fixed by the sensitivity of the instrument which must be used in a given instance. When using a standard oscillograph vibrator, $r_G = 1$. For

the coefficient to be close to unity in value, r_1 must be very large in comparison with r_G. By placing $I_G = 0$ in equation (1) of Fig. 4, it will be seen that the term $\frac{e}{r_1 + r_G}$ then represents the steady component of the plate current for which compensation must be made.

$$I_p \frac{r_1}{r_1 + r_G} = \frac{e}{r_1 + r_G},$$

or

$$I_p = \frac{e}{r_1}.$$

From this it appears that for any given value of I_p for which compensation must be made, r_1 is directly proportional to e. Thus, for r_1 to be large and the sensitivity of the instrument to be unimpaired by the addition of the compensation circuit, e must be large. By similar analysis, it is found that e should be as large as possible in the other cases also.

Practically, it has been found that Case I is best for oscillographic work, and Case III is best where the compensated currents are much smaller, of the order of a few milliamperes or less. Both Cases II and IV have not been found to be sufficiently flexible in adjustment without impairment of sensitivity.

TEST OF COMPENSATION BY METHOD OF CASE I.

The characteristics of the circuit of Case I were studied experimentally by connecting such a circuit across the vibrator of the amplifier of Fig. 2. In the experimental circuit investigated, e was a 20-volt storage battery with a one ampere rating. r_1 was composed of two rheostats in series, one of 355 ohms for coarse adjustment and the other of 46 ohms for fine adjustment. r_G was one ohm, the vibrator being of the standard type.

With no compensation and with the bias voltage on the amplifier input set at 2.100, the steady oscillograph deflection was 4.15 cm., equivalent to an output current of about 200 milliamperes. Under these conditions, a change of $-$ 25 mv. on the input reduced the deflection by 1.43 cm. A voltage change of $-$ 50 mv. caused a reduction of 2.63 cm.

When partial compensation was obtained by reducing the steady deflection of the vibrator by 2 cm., that is, by reducing the steady vibrator current from about 200 to 100 milliamperes, no change in sensitivity was detectable. The same sensitivity was found to obtain with complete compensation, that is, with none of the steady component of the output current flowing through the vibrator. Further, the sensitivity with over-compensation was found to be only one or two per cent. different from the value with no compensation. The compensating circuit supplied the current through the vibrator when over-compensation was made, and the deflection was opposite to that caused by the amplifier output.

This fortunate circumstance that sensitivity is relatively independent of the degree of compensation may be understood by noting the values of the sensitivity constant in Case I for the several instance mentioned. In the first, where the compensation was partial, r_1 was about 200 ohms and the constant was about 0.995. With full compensation and over-compensation, the constant had a value of about 0.99.

The conclusion to be drawn from these studies is that the adjustment of the compensating circuit of Case I is not critical provided the voltage of the auxiliary battery in the compensating circuit is made sufficiently high. Also, with the same proviso, the sensitivity of the instrument is not appreciably impaired by the addition of the compensating circuit. Here, as in other portions of the circuit of the amplifier-oscillograph, constancy of conditions is the prime consideration.

THE PROBLEM OF INTERFERENCE.

With high-gain amplifiers, the problem of interference often assumes serious proportions, and in some applications, it is the factor limiting the amount of amplification which can be used. Interference arising from methanical vibration must be eliminated by the obvious means of cushioning either the source of vibration or the amplifiers or both. Electrical or magnetic interference is more difficult to eliminate and therefore, more serious. Electrostatic shielding is helpful and often entirely effective when properly grounded. Sometimes interference having a frequency of five to ten thousand cycles per second can be suppressed by the introduction of a

grid leak of about 0.5 megohm in the input grid lead, as is shown in Fig. 2. This arrangement suppresses these higher frequencies but as a consequence also limits the reproduction of the higher frequencies by the instrument. The upper oscillogram of Fig. 5 shows the excellent reproduction of a

FIG. 5.

complex wave form by the amplifier of Fig. 2. The lower oscillogram shows how the quality of reproduction was impaired by the introduction of 500,000 ohms into the input grid lead.

SOME PHOTOGRAPHIC CONSIDERATIONS.

A not insignificant factor in precise oscillographic measurements is the distinctness of the oscillographic record. Care should be taken to observe the more fundamental principles

of photography involving the balancing of the intensity of the light source, time of exposure of the film as affected by the film speed, and the photographic sensitivity of the film used. With the introduction of orthochromatic film in this country for amateur photography, sold as Agfa Plenachrome film and Eastman Verichrome film, it has become relatively easy to obtain it for oscillographic work requiring high film speeds. By employing a very caustic process film developer[4, 5] and orthochromatic film, excellent oscillograms have been obtained at film speeds of 25 ft. per second with an incandescent lamp as the light source. At this speed, a single cycle of a 60-cycle alternating current is spread over five inches of film, allowing accurate analysis of its wave form. It does not seem that any further advantage would be derived from the use of the very sensitive panchromatic films, because of the practical limitation set upon film speeds by the frequencies to which vibrators can respond. Any additional accuracy that might come in measurement of films with greater resolution of the time axis would be nullified by the inherent distortion of the vibrators at the frequencies where the resolution might prove beneficial.

SOME TYPICAL APPLICATIONS.

The amplifier-oscillograph in its various forms has many useful and interesting applications.

Figure 6 shows a group of oscillograms taken to study the wave form of the high voltage applied to some cable samples. The interesting point about this group is that they were obtained by connecting the amplifier input across a resistance in the ground lead of a sphere gap. The current value represented by the maximum value of the topmost wave is about 36 microamperes. As the spacing of the gap was smaller when the two lower films were obtained, their peak values represent currents of about 90 microamperes. The oscillograms show how increasing the capacitative load, together with the inherent inductive reactance of the supply transformer, improved the wave form of the high voltage.

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[4] C. B. Neblette, "Photography—Its Principles and Practice," 2d Ed., D. Van Nostrand Co., New York, 1931, p. 531.

[5] "Book of Formulas for Professional Films and Plates," Eastman Kodak Co., Rochester, N. Y., 1930, p. 6.

FIG. 6.

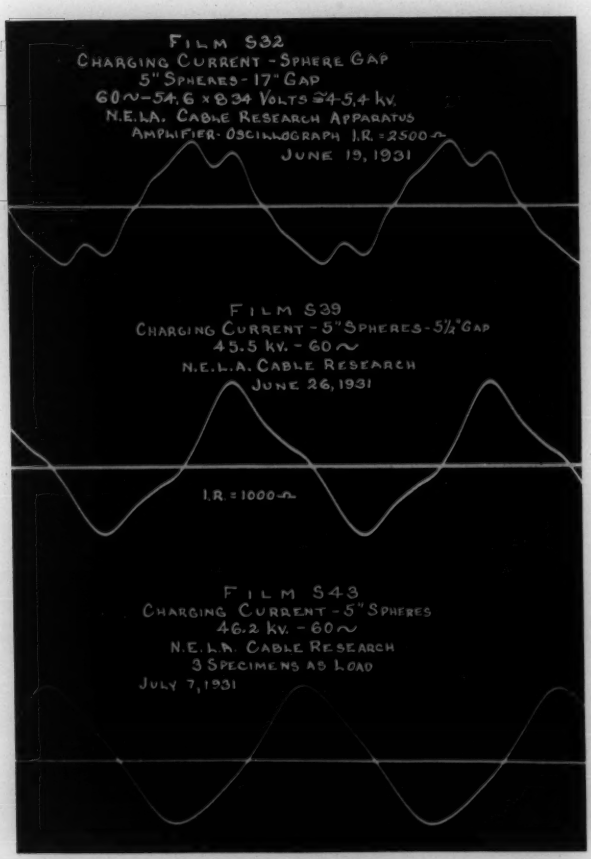
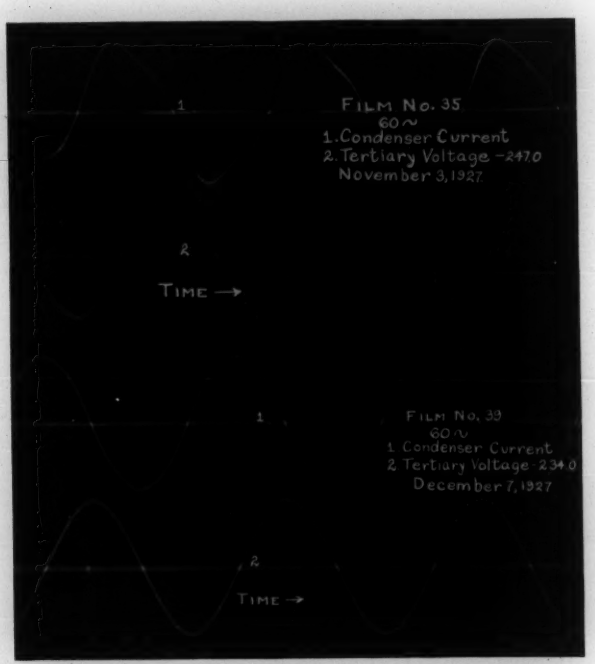

FILM S32
CHARGING CURRENT - SPHERE GAP
5" SPHERES - 17" GAP
60~ - 54.6 x 834 VOLTS = 45.4 kv.
N.E.L.A. CABLE RESEARCH APPARATUS
AMPLIFIER-OSCILLOGRAPH I.R. = 2500~
JUNE 19, 1931
FILM S39
CHARGING CURRENT - 5" SPHERES - 5½" GAP
45.5 kv. - 60~
N.E.L.A. CABLE RESEARCH
JUNE 26, 1931
I.R. = 1000~
FILM S43
CHARGING CURRENT - 5" SPHERES
46.2 kv. - 60~
N.E.L.A. CABLE RESEARCH
3 SPECIMENS AS LOAD
JULY 7, 1931

Figure 7 was obtained in a study of a similar nature made to detect the presence of parasitical corona on a high voltage system operating at about 98,000 volts. Here the wave form is that of the charging current of an air capacitor, in which the presence of corona elsewhere on the system causes a character-

FIG. 7.

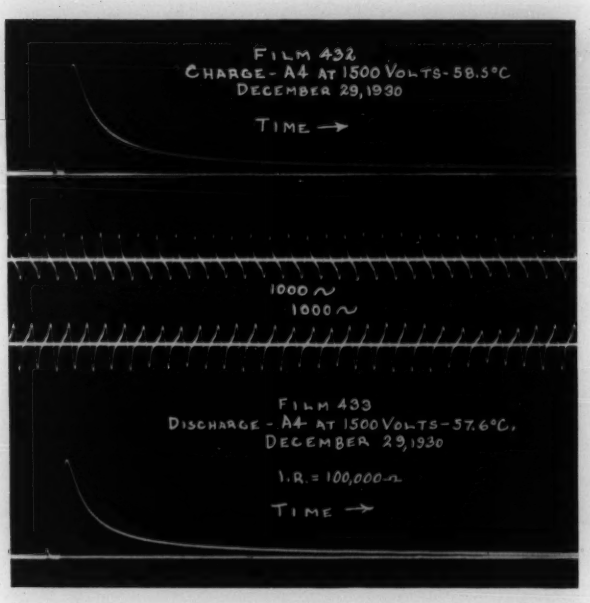


istic high frequency ripple in the upper oscillogram. The lower oscillogram shows the relatively pure sine wave obtained after the system had been modified and the parasitical corona removed. Without the amplifier-oscillograph such studies would have involved a complicated apparatus for obtaining

sufficient current from the high voltage system to operate an oscillograph vibrator.

Figure 8 shows a typical pair of d.c. charge and discharge records made on a dielectric sample of dried paper. The currents represented by the initial peaks of these curves is 1.5

FIG. 8.



microamperes. For this work, the measurements were as precise as could be made, which necessitated special precautions in the procedure. It is planned to describe these at some future time.

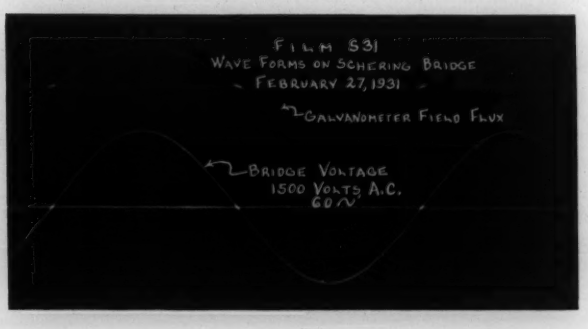
Figure 9 shows the effect on the charging current of a small paraffin sample when ionization occurred in voids within the

FIG. 9.

material. Here irregularities in the wave form appeared when the applied voltage exceeded a given value.

Figure 10 is the result of a study of the wave form of the magnetic flux in the gap of a dynamometer type of a.c. galvanometer. To obtain this record, the suspension of the moving galvanometer coil was lowered and the coil placed with its plane as nearly as possible perpendicular to the magnetic flux. The amplifier was connected directly to the terminals of the coil. The amplifier-oscillograph recorded the voltage induced in the coil, and thus gave an indication of the wave form of the magnetic flux. The peak value of the upper wave represents an induced voltage of 58 millivolts.

FIG. 10.



ACKNOWLEDGMENT.

The major part of the experience which has been summarized here was gained while engaged upon a research problem sponsored by the Utilities Research Commission of Illinois under the supervision of Dr. J. B. Whitehead. To them the author wishes to make due acknowledgment of the support given.

SUMMARY.

If the amplifier-oscillograph is to attain the fidelity of frequency reproduction of the unaided oscillograph, the amplifier circuit must be designed, constructed, and used with discretion. In no portion of the circuits, in neither the amplifier itself nor the connected measuring circuits, is it permissible for the associated resistances, capacitances, and inductances to produce time constants so large as to suppress any of the frequencies which the oscillograph vibrator would reproduce normally. Steadiness of the amplifier is a prime consideration, usually attainable with moderately high gain units by having sure electrical contacts and the component parts operated conservatively within their respective ratings. Interference is frequently a source of considerable difficulty and great care must be exercised not to permit it to cause erroneous measurements.

A method of compensating for the steady component of the amplifier output current has been investigated and when properly used, has been found neither to impair the sensitivity of the instrument appreciably nor to require critical adjustment.

Consideration also has been given to the photographic technique involved in oscillography in order that its full possibilities might be realized.

An instrument has been described and discussed which had a sensitivity of about 1.7 millivolts per mm. deflection. When the maximum permissible input resistance of 0.1 megohm was used, a current sensitivity of about 1.7×10^{-8} amperes per mm. deflection was attained. A greater value of input resistance could not be used without the possibility of introducing serious distortion.

THE TUNGSTEN LAMP.

BY

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The lamp engineer has as his problem the conversion of electrical energy into light in the most efficient manner possible; he wants to get as much light for the power used, that is as many lumens per watt as he can, together with a satisfactory source of light. The satisfactoriness, i.e., ease of operation and appearance, of a source of light is more important than it is sometimes considered. It is safe to say that almost no one would use as a source for general lighting anything that was less pleasing from the standpoint of color and less simple to operate than the present incandescent lamp, even if it were a great deal more efficient. The operation of the modern incandescent lamp is so simple and it is so convenient to use that one often fails to think of its great convenience.

Edison used carbon as the filament for his incandescent lamp because it was the best material that he could find for this purpose. Many attempts had been made before Edison's successful solution of the problem to make an incandescent lamp using some of the well known metals such as platinum for the filament but they were not satisfactory. From a knowledge of how substances radiate when heated it was early recognized that all other things being equal, the higher the temperature the better the light source, both from its appearance as to color and from its efficiency. Almost as soon as Edison brought out his incandescent lamp attempts were made to improve the carbon filament and to find a better material than carbon for the filament. A process of squirting [1] the carbon filament from a paste was developed which gave a much more uniform filament than those obtained from carbonizing threads or strips of bamboo. Dr. Whitney [2]

[1] Powell, "History of the Incandescent Lamp," Howell & Schroeder, p. 81.
[2] "History of the Incandescent Lamp," Howell & Schroeder, p. 84.

developed a method of improving the quality of the carbon filament by a process of heat treatment. The result of these improvements was an increase in efficiency from about 5 watts per mean horizontal candle (2 lumens per watt) for Edison's early lamp to about 2 1/2 watts per mean horizontal candle (4 lumens per watt) for the treated carbon filament. Thus improved, the carbon filament held the field for about twenty-five years.

The Nernst glower which consists of a mixture of some rare earth oxides was the first real competitor of the carbon lamp but it is doubtful if it every could have been developed to a point where it would have been able to displace the carbon filament lamp. However, shortly after it was introduced other substitutes were suggested which were even better than the Nernst glower. Tantalum and osmium were both used as filaments. These were found to be about twice as efficient as the old carbon lamp but only about 20 per cent. more efficient than the treated carbon filament which they were attempting to replace. None of these were able to compete with the metal tungsten when it was introduced as a lamp filament material.

A substance, in order to make a good lamp filament, must so radiate that as much as possible of the energy is in the visible portion of the spectrum, and in addition, it must be a material that can by some means be made into a filament that is strong enough to permit mounting and to stand up under the condition of use. Up to temperatures well beyond those attainable with any known substance the proportion of the energy radiated in the visible spectrum increases with an increase in the temperature. Thus a high operating temperature is desirable. Tungsten satisfies these conditions the best of any substance known because it has a very low vapor pressure which permits operation at very high temperatures and because it radiates selectively in favor of the visible spectrum. Despite many statements to the contrary, no substance is known, either an element or a compound, that satisfies the radiating conditions for a life beyond a few hundred hours as well as tungsten and this does not take into consideration some of the other valuable properties of tungsten as a filament material. This point should be stressed; there is no

substance known today that can be used as a lamp filament that is as efficient as tungsten for a converter of electrical energy into light on the basis of a life beyond a few hundred hours and no reservations are made as to cost, difficulty of manufacture, or any other considerations.

The filamentless lamp, i.e., gaseous discharges and enclosed electrical arcs have been experimented with for the past forty years. At one time this sort of lamp was considered very important, so much so that the New York Post Office was lighted with the Moore gas discharge tubes. However, this early type of lamp did not prove to be as convenient or as efficient as the tungsten lamp. Indeed, about the only source of this kind that has been found sufficiently satisfactory to compete at all with the tungsten lamp is the mercury arc and even this source only in large units and for installations where the color of the light is not objectionable. Even today with all the advances in the knowledge of the radiating and operating characteristics of gaseous discharge and enclosed arc no method is known of making a lamp for a few hundred hours life that is but a small amount more efficient than the tungsten lamp, and even for this gain in efficiency one must accept a green or a yellow light. It must not be understood from the above that the problem is closed because some day someone may find a substitute for tungsten as a filament material, or many learn how to make a filamentless lamp that is more efficient and as satisfactory as the present tungsten lamp. However, notwithstanding all that has been published and reported concerning the efficiency and the satisfactoriness of filamentless lamps to date there is not a single lamp of this type known that is as satisfactory as the tungsten lamp on the basis of life, ease of operation, and the quality of the light. It is a rather remarkable situation that for the past fifty years the incandescent lamp has maintained its position as the leading source in the field of general lighting and what is more remarkable is the fact that during this entire time the lead has been maintained by the use of but two types of filament, that is, the carbon filament for about the first twenty-five years and the tungsten filament for the last twenty-five years.

Tungsten was not chosen as the material for the present day lamp filament by any accident but it was chosen because it

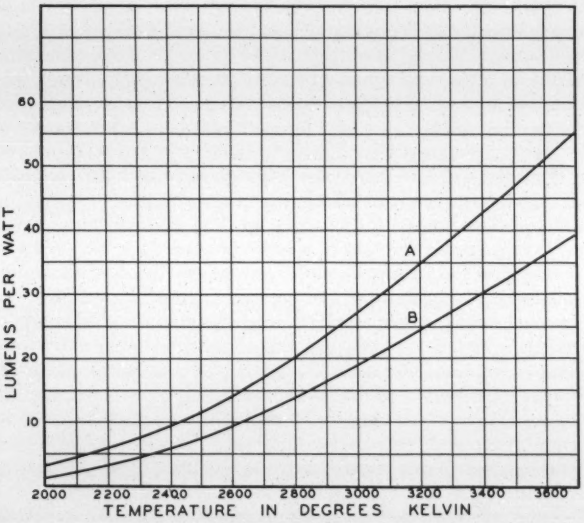
possesses some outstanding properties among metal that makes it very valuable for this purpose. Some of these properties were unknown when it was first used as a filament and even then though no method was known of using at least two of its properties no other metal or compound was able to compete with tungsten as a lamp filament. The outstanding properties that makes tungsten valuable for this special purpose are: (1) Favorable radiating characteristics. (2) Lower vapor pressure and high melting point. (3) High tensile strength, and (4) its ductility. It is also fortunate that there is a sufficient supply of the metal so that filaments are not excessive in cost. When tungsten was first used as a filament no one knew how to make ductile tungsten wire. A method of making tungsten wire of almost any diameter desired was discovered in a very extensive investigation by Dr. Coolidge [3] at the General Electric Research Laboratory at Schenectady. The discovery of the method of making ductile tungsten wire was a very important step in lamp making. The old squirted filaments were very difficult to make and even at best these filaments were very fragile. It is hard to imagine how the present day lamp with all its exacting specifications could be made if drawn tungsten wire were not available. The use of drawn tungsten wire for the filaments enabled lamps to be made for a very definite current and voltage operation. Some of the incandescent lamps require filaments of very small diameter. The filament of the forty watt 115 volt gas-filled lamp is only about 1.5 mils (0.035 mm.) in diameter and a 5 watt 115 volt lamp requires a filament that is only about one-tenth the diameter of the average human hair that is only about .3 mil (007 mm.) in diameter!

Curve *A*, Fig. 1, shows as a function of its temperature the efficiency of tungsten as a light source. These data refer to the efficiency as a function of temperature of a filament mounted in a vacuum where the filament is long enough so that any losses due to heat conduction by the leads or supports may be neglected. Curve *B* of this same figure shows as a function of the temperature the efficiency of the black body as a light source.

[3] *A. I. E. E. Journal*, 29, 961, 1910.

The lamp engineer is constantly striving to find methods of manufacture that will enable him to make a lamp for the designed life with as high an efficiency as possible and at the same time to secure as uniform a product as possible. This desire to secure a uniform product has been largely responsible for the introduction of so many machine processes in lamp

FIG. 1.



Curve *A* shows the variation of efficiency of tungsten with temperature. Curve *B* shows the variation of efficiency of a black body with temperature.

making. It can be safely said that not a single machine has been introduced in any of the processes of manufacture of lamps or lamp parts that has not resulted in both a better lamp and a more uniform product. Those in the lamp industry are of the opinion that the quality of no modern product is any more jealously guarded than that of the incandescent lamp.

Since tungsten filaments are the best to use and since the life is determined in general by the rate of evaporation of the filament the engineer is constantly searching for a method of reducing the effectiveness of the evaporation and of reducing the other losses of energy and light. Among the more serious losses that the engineer has to deal with are: (1) Heat conduction by the leads and supports. (2) The IR drops in the leads, and (3) The absorption of light by the bulb and the base of the lamp. Also the lamp bulb and the filament must be strong enough so that they will not be broken in the ordinary handling necessary in shipping and in use. Thus the lamp engineers must study means of strengthening the bulb and the filament as new hazards of use develop. He has as his goal the making of the very best lamp that it is possible to manufacture for the particular service for which the lamp considered is intended. As an example, a rough service lamp is made which, while it is not as effecient as the lamp of corresponding wattage that is used for general lighting, is much more satisfactory to use on the end of a long drop cord.

The first major improvement in the efficiency of the tungsten lamp resulted from a successful attempt to reduce the rate of the evaporation of the filament so that it could be operated at a higher temperature and thus at a higher efficiency. Before tungsten had replaced carbon as a lamp filament attempts were made to increase the operating temperature of the carbon filament and thus its efficiency by reducing the rate of evaporation from the carbon filament. It was reasoned that if the carbon filament were surrounded by a high pressure of some inert gas the rate of evaporation would be reduced to such an extent that it could be operated at a higher temperature which would result in an increased efficiency and still maintain the one-thousand hours life. It was known of course that if the carbon filament could be operated at a higher temperature the efficiency would be greatly increased. This attempt to operate [4] the carbon filament in an atmosphere of argon was made and it was found that while the carbon filament would operate at a much higher temperature for the one-thousand hours life, it was, under these conditions, if anything, less efficient than the vacuum lamp because the

[4] R. Gordon, University of Wisconsin thesis, 1909.

losses due to the conduction and convection by the surrounding gas more than made up for any gain in efficiency due to the operation at a higher temperature. Langmuir [5] made a study of this problem and found that with respect to loss of energy filaments of different diameters when operated in an atmosphere of an inert gas acted as though they were surrounded by a more or less stationary sheath of gas and that the percentage gas loss was much less for filaments of larger diameter. He showed that these losses were markedly reduced by coiling the filament into a helix since the gas losses depended upon both the diameter and the overall length of the coil and not that of the wire. By this method a 500 watt gas-filled lamp was then made that was about fifty per cent. more efficient than the corresponding vacuum lamp. As a result of Langmuir's work the lamp engineer was given a great advantage and also was given further difficulties to overcome.

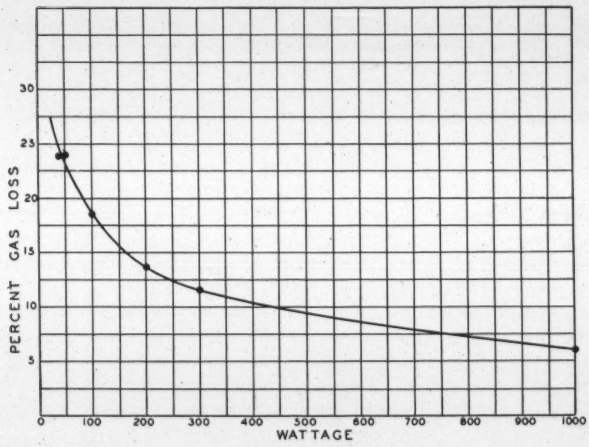
The gas first used in these gas-filled lamps was nitrogen. It was early recognized that some of the inert gases would be more satisfactory for this purpose since their heat conductions are considerably less than that of nitrogen. Twenty years ago one would hardly have hoped that sufficient argon could be obtained at a price that would permit it to be used as a gas in the present day gas-filled lamp. Again the lamp engineer worked out ways and means of obtaining the necessary argon so that most of the present gas-filled lamps have an atmosphere that is made up of about 80 per cent. argon and the remainder nitrogen. The requirements of the gas used with respect to its purity and freedom from water vapor are very rigid. The reason for this is that some of the impurities that are naturally present react with the tungsten filament and reduce its strength and may even increase its rate of evaporation. How serious this gas loss is for small lamps is is shown by the curve in Fig. 2 which gives the per cent. gas loss for different size lamps.

The loss of heat by the conduction of the leads and support in the older type of 115 volt lamp amount to about 4 per cent. of the input energy which resulted in an efficiency loss of about 7 per cent. This has been reduced until at the present time the energy lost by the end conductions amounts to

[5] *A. I. E. E. Journal*, **32**, 1931, 1913.

about 2 per cent. for the 115 volt lamp of ordinary size. This reduction in energy loss has been brought about by using different materials for the leads, using different and smaller wires for the supports and by eliminating as many of the supports as possible. Improvement along these lines have been largely due to an improved quality of the filament wire with respect to its non-sagging properties. The lamp engineers have developed a wire that will retain its shape at high temperatures much more satisfactorily than the older wire. Some

FIG. 2.



Gas-losses for different wattage lamps.

data on the end losses of present day lamps are included in Table I.

It was at first quite difficult to coil the wire that was then being used for lamp filaments and have these coils retain their shape when they were operated at high temperatures. It was found possible to improve the qualities of the wire so that not only could it be made into a coil but the diameter of the coils could be increased and the resulting coiled filaments retain their shape when operated at a high temperature without as

TABLE I.

Some Characteristics of Incandescent Lamps.

Lamp.	Number of Supports.	Temperature Degrees K.	Efficiency Lumens per Watt.	Percentage of Input Radiated Within Visible Spectrum.	End Loss, Per cent. of Input Conducted by Leads and Support.	Gas Loss Percentage of Input.	Percentage Input Radiated Bulb by Filament.	Percentage Efficiency Loss Due to End Loss.
25 Watt Vacuum.....	3	2535	10.2	7.0	1.8		91.2	2.8
40 Watt Gas-Filled.....	3	2710	11.	6.8	1.9	24.5	66.8	2.8
60 Watt.....	3	2750	12.3	7.6	2.5	22.2	69.1	5.0
100 Watt.....	3	2800	14.3	8.5	2.3	18.5	72.8	4.5
200 Watt.....	3	2855	16.5	9.7	2.4	13.7	77.4	4.8
500 Watt.....	3	2965	19.6	11.7	2.1	9.2	82.3	4.3
1000 Watt.....	5	2995	20.5	12.0	4.8	6.0	82.1	8.8

many supports as formerly. The removal of a single support from an ordinary tungsten lamp results in an increase in efficiency of about 0.5 per cent. The old 40 watt vacuum tungsten lamp had eleven supports while the new gas-filled lamp of the same size has only three supports. This change alone accounts for about 4 per cent. gain in efficiency.

The life of a lamp with a tungsten filament at a given temperature increases with an increase in the filament diameter since the cross section of the filament which determines the resistance and thus the variation of the temperature depends upon the square of the diameter while the amount of material vaporized depends upon the surface used which, in turn, varies directly as the diameter. Since in general 115 volt lamps of all sizes are operated for approximately one-thousand hours life this means that the larger filament lamps can be operated at a somewhat higher temperature for the same life which again means that the larger filament lamps operate at a higher efficiency than the smaller lamps.

Just why one thousand hours has been selected as the standard life of incandescent lamps is difficult to say. The customer is not only buying lamps but is also buying electric power for the purpose of obtaining light and he should use the lamps and electric power to the best advantage possible. It is obvious that if the electric power cost nothing the lamps should be burned for a very long life, the life in this case being

determined by the quality of the light desired. On the other hand, if the lamps cost nothing they should be so operated as to have a very short life, the life in this case being determined by the value placed upon the time necessary to change the lamp. Since one pays for both the lamp and the electric power some compromise is necessary. It is possible to operate the lamp at such an efficiency that the life will be so long that the cost of power will be excessive for the light obtained, or again, the lamp may be so operated that the life will be so short that the cost of the lamp will be excessive for the amount of light obtained. Due to the relation between life of the lamp and its efficiency a life of the lamp can be found for which the cost of the light in cents per thousand lumen hours will be a minimum whatever the cost of the electric power and the lamp. The actual operating condition for a minimum cost of light will be changed if a charge is inserted for the time taken to change the lamp but a minimum can still be found for any fair value of this nuisance charge. Considering the present price of lamps and of electric power the 115 volt lamps used in general illumination should be operated at an efficiency that will give a life of about six hundred hours. At this life the customer would pay a smaller price for the lumen hours of light that he obtains than for any other condition of operation.

To reduce the glare from the bright filament it has been the custom for a long time to frost or enamel the outside of the lamp bulb. There are two objections to this method of reducing the glare. One is that the frost being on the outside of the bulb is somewhat rough and it is very difficult to clean and also it was found that these frosted and enameled bulbs even when clean absorb from 5 to 20 per cent. of the light from the lamp and this absorption of light might be very high when the bulb becomes covered with dirt. It was early recognized that if the bulb were frosted on the inside it would be much easier kept clean but the early attempts at this failed because the bulb frosted on the inside was very much weaker than if frosted on the outside. One of the lamp engineers [6] studied this problem and devised a means of frosting the lamp on the inside in such a manner that the bulb is practically as strong

[6] Pipkin, *Industrial and Engineering Chemistry*, 18, 774, 1926.

after frosting on the inside as it was before. The absorption due to the inside frost amounts to, in general, about 1 per cent. of the light from the lamp. Thus the replacement of the outside frost by this inside frost has resulted in a saving of 4 to 5 per cent. in efficiency over the old outside frost bulb and at the same time has given us a lamp that can be cleaned as readily as the clear bulb.

Some time ago the lamp engineers decided that it would be advantageous to replace all clear bulbs with inside frost bulbs and at the same time to use coiled filaments for some of the vacuum lamps rather than the customary straight wire because this would permit them to make a much smaller bulb for the same wattage lamp. At the time they started they expected to make a vacuum lamp with coiled filament that would be about as efficient as the straight filament vacuum lamp that it was intended to replace. It was known that a coiled filament was inherently a poorer source of light than the straight filament when they were both operated at the same temperature because while tungsten radiates selectively in favor of the short wave-lengths, when the filament is coiled, part of the radiation from the space between coils approximates that of the black body which is a less efficient producer of light than tungsten. The loss in efficiency due to the partial black body radiation from the inside of coils and the small amount of light absorbed by the inside-frosted bulb combine to lower the efficiency of a vacuum lamp with a coiled filament. However, there are other factors that tend to increase the efficiency. Two of the latter are outstanding. The rate of evaporation from a coiled filament is considerably less than that from a straight filament at the same temperature because many of the tungsten molecules that leave the inside of the coils strike the filament and are unable to escape. This difference permits the operation of the coiled filament at a higher temperature for the same life. As previously mentioned, the coiling of the filament permits the number of supports to be reduced from nine to three, and this change results in about a three per cent. increase in efficiency.

Another factor gives an additional though slight gain in efficiency. Because of the mutual heating effect between coils, the same current will heat a coiled filament to a higher

temperature than the corresponding straight wire. This means that with coiled filaments a slightly larger filament can be used for the same temperature and the same wattage. As pointed out above, the life of a lamp at a definite temperature depends upon the cross-section of the filament. Thus, the use of the larger filament permits it to be operated at a slightly higher temperature for the same life and this results in an increase in efficiency.

The combined effect of these properties of the coiled filament and inside frosting was a gain in efficiency for the new inside frosted lamp with a coiled filament over the old straight filament type of tungsten lamp in a clear bulb.

Now just why is all this effort being expended in an attempt to increase the efficiency of the light source and all the agitation about such an increase in efficiency? The reason for this is that of all the problems that are occupying the engineers today the one connected with the light source offers the greatest opportunities for improvement since the light source is probably the least efficient from the standpoint of the ultimate that can be obtained of any of the converters of energy. If it were possible to use energy in the most efficient way to produce light the result would be an efficiency of about 620 lumens for each watt expended. This factor, 620, results from the definition of the lumen or the candle upon which the lumen is based. To obtain this maximum efficiency it is necessary to find some method of converting the electrical energy into radiation at the wave-length for which the eye has the maximum sensitivity, that is, in the yellow green for wave-lengths about 5560A. When it is remembered that the present day light sources range in efficiency from about 10 to 25 lumens per watt it will be noted that for these light sources the percentage of maximum possible efficiency is indeed low, ranging from about 1.6 per cent. to about 4 per cent. The light from a source operating at this maximum efficiency would be a yellow green in color which would not be satisfactory for general purposes.

If we consider a black body as a source of light and operate it at a temperature at which it has the maximum efficiency the result will be a white light at an efficiency of about 85 lumens per watt when the black body is at a temperature of about

6700° K. This results from the fact that as the temperature of a radiator is raised the maximum of the radiation shifts toward shorter and shorter wave-lengths. This at first gives an increase of the percentage of the energy within the visible spectrum and with still higher temperature the maximum of this energy moves to the ultraviolet which reduces the percentage radiated in the visible spectrum and thus the efficiency. This efficiency of 85 lumens per watt might be increased somewhat if it were possible to eliminate the infra-red and ultraviolet radiation that are not used for producing the light. If the ultraviolet were eleminated for wave-lengths shorter than 4000A and the infra-red for wave-lengths longer than 7600A the efficiency would be increased to about 200 lumens per watt. This efficiency might be increased up to as much as 250 lumens per watt without very greatly changing the color of the light by changing these limits, the one towards longer wave-lengths and the other towards shorter wave-lengths. Since other sources are at least as efficient as the black body a marked gain in efficiency would result if light sources could be operated at a very high temperature, and if, in addition to this high temperature operation, some method could be devised to eliminate the ultraviolet and particularly the infra-red radiation another increase of a factor of 2 or 3 would result. Quite unfortunately no one knows how to make a black body or any other source that can be operated at a temperature of 6700° K and thus obtain the 85 lumens per watt, nor is it known how to suppress the ultraviolet and infra-red part of the spectrum, thus increasing this by a factor of 2 or 3.

The amount of energy within the limits of the visible spectrum for the various tungsten lamps is small. In column 3, Table I are given the percentage of the input energy that is radiated within the limits of the visible spectrum for several different wattage lamps. From this it is seen that the lamp engineer has plenty of incentive to attempt to find a source that will radiate more favorably than the tungsten lamp, that is, a source that would give a larger percentage of its radiation in the visible spectrum. There is also plenty of work to be done in reducing some of the losses in addition to the work to be done in studying designs and methods of manufacture.

Such changes are continually in progress. As an illustration of the progress made by the lamp industry the following example is given: In about 1909 or 1910 the temperature and efficiency were measured [7] of some forty watt tungsten lamps with squirted and drawn wire filaments. The results are given in Table II together with like data on the present 40

TABLE II.

Comparative Measurements on 40 Watt Lamps.

Lamp.	Date Measured.	Temperature.	Efficiency in Lumens/Watt.
40 Watt Squirted Filament.....	1909	2310° K.	8.4
40 Watt Drawn Wire.....	1909	2320° K.	8.9
40 Watt Vacuum.....	1931	2565° K.	10.8
40 Watt Gass-Filled.....	1932	2610° K.	11.

watt lamp for comparison. Like improvements have been made in other wattage lamps. An increase of 30 per cent. in efficiency of one type of lamp over a period of about twenty years may not seem large but when applied to the total light bill of the country its value becomes quite significant.

The idea of a filamentless lamp is attractive because the radiation from some of the gases and vapor used consists of lines or bands located in very favorable portions of the spectrum. The radiation from the mercury arc consists of a number of lines and one of the strong lines is located near the wave-length of maximum sensitivity of the eye. If this were the only line radiated the arc would of course be very efficient, but unfortunately this is not the case. A number of the lines radiated are in the ultraviolet and infra-red portions of the spectrum. Some recent work by Benford [8] shows that about 6 per cent. of the energy radiated by the mercury arc is in the ultraviolet portion of the spectrum, about 7 per cent in the visible spectrum, and the remainder in the infra-red. Although the major portion of this energy in the visible spectrum is radiated by the one line that is near the position for maximum efficiency an efficiency much higher than about 50 lumens per watt should not be expected from a mercury arc

[7] *Physical Review*, 34, 341, 1912.

[8] *J. Mot. Pict. Eng.*, 14, 409, 1930.

for the very best conditions of operation unless again we can find some method to operate it so as to suppress at least a portion of the radiation in the infra-red and ultraviolet portions of the spectrum.

Another very attractive filamentless lamp is the sodium arc. The sodium arc radiates two lines in the yellow portion of the spectrum that are again very near the position of maximum sensitivity of the eye. There are no data available that give the percentage of the total energy radiated by the sodium arc in the different portions of the spectrum, but some figures seem to indicate that a large portion of it is in the two lines in the visible spectrum. If this is the case a very high efficiency could be expected from such a lamp if means could be found to overcome some of the inherent difficulties with such a source.

Neon, when used as a source of radiation for a filamentless type of lamp radiates a number of lines that are located in the red portion of the spectrum where the eye has, on the average, about 15 per cent. of its maximum sensitivity. No figures are available giving the percentage of the energy radiated by this source in the different portions of the spectrum so an exact analysis can not be made. However, what data there are seem to indicate that there is a large proportion of the radiated energy in the red lines. However, the 15 per cent. visual efficiency of the radiation will reduce the value somewhat.

Many other gases and vapors have been experimented with as sources in filamentless lamps. Under certain conditions of operation some of these gave very intense white light. However, there seems at present to be unsurmountable difficulties in the way of their use. The efficiency is low and the method of operation is very difficult and unsatisfactory. An enormous amount of work on both the problem of finding a substitute for tungsten as a lamp filament and the investigating of various materials for sources in filamentless lamps has been done and is at present under way. Notwithstanding all of this it still must be said that there is no method known for making a light source that is under the conditions of operation and use as satisfactory and as efficient as the present day tungsten filament lamp.

February 2, 1932.

Didymium Goggles.—(*Ceramic Industry*, Feb. 1932.) Didymium, a chemical element, classed among the rare earth metals, can, in the form of its oxide, be used as a constituent of glass. Its presence in the glass, gives the latter the particular ability of filtering out the yellow light rays at the time permitting the unaltered transmission of other colors. Goggles made of such glass, pinkish in color, have proved a boon to glass blowers. Anyone who has worked glass containing appreciable amounts of soda will appreciate a device which will dispel the yellow glare of flame that almost completely masks the work. Use of such goggles permits the eye to behold the glowing red glass distinctly and allows the worker to follow closely the progress of the operation.

T. K. C.

Something New in Fertilizers.—B. G. KLUGH in *Chem. and Met.* for Feb. 1932 describes the development and preparation of a new fertilizer commercially available in an improved form. The fertilizer contains anywhere from 60 to 70 per cent. total plant food consisting of the three ingredients, potash, nitrogen and phosphorus. In addition to this outstanding feature of high plant food content the preparation comes in a form especially suitable for application by drilling. The individual granules are 5/64″ in diameter and 1/8″ in length and will not " cake up " on prolonged exposure to atmospheric conditions.

T. K. C.

Magnetic Suspensions.—In *Chemistry and Industry* for Feb. 26, 1932, there is described a type of magnetic suspension for galvanometer coils as developed and adopted by a well-known firm manufacturing scientific instruments. By virtue of a special arrangement of a soft iron core and two soft iron discs lying within the field of the galvanometer magnet a mutual repulsion between the magnetized core and the two connected discs is secured. The galvanometer coil is suspended by and pivots upon jewelled bearings attached to these discs which virtually float upon a cushion of air. Since the coil is thus suspended from the instrument proper by the resilient lines of magnetic forces, it is well insulated against injury from shocks.

T. K. C.

ON THE EVOLUTIONARY ORIGIN OF THE SOLAR SYSTEM.

BY

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In the past several years a greatly increased interest in the problems of astrophysics has been manifest. As a result, the fund of astrophysical knowledge has been greatly extended and the philosophical implications have grown apace. Yet, strangely, the conclusions of a certain school of astrophysicists regarding the origin of the solar system have in a sense forced us to a pre-Copernican geocentric philosophy; for that school believes that the generation of our solar system was the result of an "accident" so improbable that our planetary system could well be the only one in the universe and man's existence here on earth unique. We find it difficult to accept, unquestioning, a conclusion so opposed to the trend of modern thought and to believe that a system so highly organized as the solar system could have come into being as the result of a highly improbable accident. We have therefore reëxamined the bases for the currently accepted theories in an attempt to formulate a more satisfactory theory of the origin of the solar system. The result places the origin of the planets as an integral part of an evolutionary process which we have reason to believe must be quite common in the universe. We may caution the uninitiated that the type of physical problem we are attempting to solve is a difficult one; we have as our guides merely astronomical observation of the present state of the system from which we must attempt by sound physical reasoning to deduce the initial condition and past history of the system. Our information is, at best, incomplete and we must assemble our jig-saw puzzle with the clear realization that perhaps many segments are missing. We first examine some of the observational material on which we are to build.

CHARACTERISTICS OF THE SOLAR SYSTEM.

The solar system is evidently not an accidental aggregation of stray bodies captured by the sun, and it seems clear that the entire system, with perhaps an occasional exception, must have had a common origin. The most noteworthy of the regularities and characteristics which must be accounted for in any complete theory of the origin of the system may be enumerated as follows:

(1) The large ratio of the mass of the sun to that of the planets and their large mass ratio to their own satellites.
(2) The direction of revolution of all the planets is the same.
(3) The orbits of the planets lie in nearly the same plane.
(4) The planetary system is dispersed over a region very large compared to that occupied by the sun, while the planetary satellite systems are relatively condensed.
(5) The equator of the sun lies nearly in the orbital plane of the planets.
(6) As far as is known, the axial rotations of the planets, save for one of the outermost, are in the same direction as their revolution.
(7) Except for the sun, and the two innermost planets, which have been particularly subject to tidal effects, the effective periods of axial rotation of all the planets are comparable.
(8) The period of axial rotation of the sun is comparatively large (31.8 days) and its angular momentum is but one-thirtieth of that of the entire solar system.
(9) The massive planet Jupiter has more than half of the angular momentum of the system.
(10) Most of the planets have systems of satellites.
(11) The more massive and less dense planets have the greatest areal velocity.
(12) The orbital eccentricities of the planets are small, while those of some of the asteroids are large.

It is upon such data as these that the theories of the origin of the solar system are builded. We must now hurriedly review some of the earlier theories and indicate briefly their difficulties.

EARLIER THEORIES.

Modern ideas regarding the origin of the solar system began to take form about 175 years ago when Kant pictured a primeval chaos condensing into a spinning nebula and, imagining the sun as one of these nebulæ, he supposed that the the planets were formed by the solidification of the gas shed from its periphery. Forty years later Laplace established this idea on a firmer basis by showing that the nebula would spin faster and faster as it condensed, take on a lenticular form, and would finally lose a ring of material which he supposed would condense and form the planets. This famous hypothesis of Laplace appeared, at first, quite plausible, but Maxwell showed in a classical paper that such a ring system could never condense. Moreover, there is a real difficulty in accounting for the present comparatively slow rotation of the sun which is about 1/50 of the rotational speed required to form such a ring system.

After it was well established that Laplace's hypothesis was incapable of accounting for the origin of the solar system, the planetesimal hypothesis of Chamberlain and Moulton was proposed and was later modified to include the essential idea of Buffon who long before had suggested that a comet might have knocked planets out of the sun by actual collision. Perhaps the most satisfactory modification of the collision theory is that due to Jeffreys who supposes that a massive star actually collided at a glancing angle with our sun and knocked out the matter from which planets were formed. His theory is unfortunately too tenuous to permit of satisfactory test by quantitative calculation.* The outstanding objection to the theory resides in the almost vanishingly small probability of a visiting star colliding with the sun in just the proper manner. Too, such a hypothesis requires the introduction of a resisting medium to account for the low eccentricities of the planetary orbits; this subsidiary hypothesis is not satisfactory since it would follow from it that the innermost planet Mercury would have the least eccentric orbit of all the planets whereas it is known to have the most eccentric orbit. However, disagreement on this one point is not necessarily fatal.

* Cf. C. V. Van Anda, *Science* 47: 187 (1931).

We may now consider some other data of astronomical observation which give us a clue to a more rational theory.

ROTATION OF THE PLANETS.

We know by direct observation that the mean density of the sun is 1.4 gms./cm^3. If we assume that the sun is of uniform density, then it follows that the sun would break up as the result of centrifugal forces if it rotated on its axis once in six hours. Moreover, the sun's angular momentum when revolving this fast would be comparable to the present angular momentum of the solar system. Observations show, too, that the period of rotation of all the planets, except the two innermost ones which have been particularly subject to tidal development, have effective periods of rotation systematically very close to this critical solar period of six hours. The major planets Jupiter, Saturn and Uranus all rotate about once in 10 hours. The axis of Uranus is tipped about 97° with respect to its orbit (presumably by a resultant tidal couple acting, for a short interval of time just after birth, about an axis different from the axis of spin) and its rotation is barely retrograde. Neptune rotates on its axis once in 15 hours. The present period of rotation of the earth is 24 hours, but its initial effective value must have been only 4.1 hours; for originally the moon was at the earth's surface and the angular momentum of the earth proper must have been correspondingly much larger than its present value. It is known that Eros spins with a period of 5 1/2 hours. Mars is an exception; but this is remarkably consistent with our hypothesis, for there are good reasons for believing that it has lost a comparatively massive satellite which possessed most of the angular momentum of the system. Moreover, it is known that Phobus revolves in a nearly circular orbit around Mars once in 7 1/2 hours and this clearly indicates that Mars once rotated much faster than it now does.

This bracketing of the solar critical period by the effective periods of all those planets which we should expect to yield useful information is perhaps the most significant of all the data we have to consider. It is a remarkably clear guide that can lead the investigator to but one conclusion: *the planetary system originated as a result of the rotational breakup of a parent star not greatly different from our present sun.*

We have, of course, neglected the effects of tidal couples and condensation on the periods of rotation of our newly formed planets; but we can advance arguments to show that these could not have greatly altered the magnitude of the rotational period from that of the parent sun. For example, we know from observed tidal data that the tidal angle of the earth is very small and that it almost immediately accommodates its form to external systems of forces. Thus tidal couples acting on the earth during the birth process were probably not large and we infer that such will be the case for the other planets, but rough calculations show that this certainly would not be true for the massive companions. And as for condensation, with a resultant change in moment of inertia and rotation period, we believe that such condensation was unimportant. The tiny satellites of Saturn, which were born simultaneously with the planet, must have cooled off almost immediately after their formation; and if Saturn has condensed appreciably from its original state, then all the satellites inside the *original* Roche limit should have disintegrated to form systems of rings. It is known that the limit between the ring system and the satellite system corresponds with really surprising accuracy to the present Roche limit of Saturn. This appears to be reliable evidence for believing that *the entire solar system was practically condensed when formed.* We therefore need not face the very serious difficulty of earlier theories which had to account for *gaseous condensation* onto discrete nuclei of initially very small mass.

The observational data which we have just emphasized suggest that we must postulate the rotational breakup of a parent star but it gives us no further clue as to the actual mechanism. Rotational hypotheses have been considered heretofore but all failed completely to explain the slow rotation of the sun and its relatively small angular momentum compared to that of Jupiter and the other outer planets. We avoid this serious difficulty of earlier theories and establish the formation of planetary systems as an integral part of the evolutionary progress of binary star systems, by showing that tidal couples due to the two components of a dividing star will convert the angular momentum of spin of the two close stars to that of orbital momentum and leave them finally

rotating very slowly about their axes. Our new theory of the solar system is therefore essentially a single aspect of a far broader subject which seeks to explain the occurrence and properties of binary star systems.

BINARY STARS.

Observational astronomy shows that at least one star out of four has associated with it a companion star of comparable mass. The chance of capture of one star by another seems far too small to account for the prevalence of star pairs and it seems necessary to assume that the pairs occur either as a result of condensation onto two independent nuclei or that they originate by fission. The fission theory, developed by Poincaré, Darwin, Russell and others, suggests that a star becomes unstable as a result of rapid axial rotation and eventually breaks up into two components of nearly equal mass. The theory together with tidal evolution accounts fairly well in its usual form for the occurrence and evolution of close or spectroscopic binary systems but seems entirely inadequate to account for the visual pairs. While the detailed calculations of the stability of a rapidly rotating liquid star by Darwin yield considerable information regarding the mass ratios of the components, the figures of equilibrium, etc., they fail to describe the process of fission; because during this most interesting interval the equilibrium is essentially unstable and events proceed cataclysmally. The qualitative picture presented by the fission theory seems, however, essentially correct.

The fission theory requires that a parent star shall rotate so rapidly on its axis that it becomes unstable. It was originally thought that this rapid rotation resulted from the original angular momentum of a parent nebula and that the condensation of a star was sufficient to account for its presence. Moulton [1] objected to this interpretation and showed that such a hypothesis leads to an improbably large ratio for the initial and final densities. His contention is further supported by the conclusion of Jeans [2] who has shown that a rotating

[1] F. R. Moulton, "Tidal and Other Problems," Carnegie Inst. Publication 107, 79 (1909).

[2] Jeans, "Astronomy and Cosmogony," Cambridge Press (1928).

and evolving star radiates angular momentum as well as mass. Another objection closely related to the foregoing has been raised by Chamberlain [3] who suggested that a rapidly spinning star will lose its atmosphere at the equator and that the lost particles will carry off angular momentum in such a manner as to stabilize it and prevent its breakup.

Still another very serious limitation of the fission theory was discussed by Jeans [2] who showed that unless the mass ratio of the two components was less than three-tenths, the angular momentum of the critical Jacobian ellipsoidal configuration of the parent star was insufficient to separate the two resulting components to regions where they could be in stable equilibrium. That is to say, if the mass ratio of the components is near unity (as is indicated by both observation and Darwin's calculations), each component will remain inside the Roche limit of the other and hence it will disintegrate as a result of tidal and centrifugal forces. Such disintegration is not observed, and we are required to believe either that binary star systems are born with a low mass ratio and by unequal radiation of mass evolve into pairs of nearly equal mass, or that the fission theory is incomplete, perhaps owing to neglect of some other forces which affect the life history of the stars.

ELECTROMAGNETIC FORCES.

Now observational astronomy definitely shows that many early type stars actually *do rotate* so fast on their axes that their surface accelerations must approach zero and therefore they are on the verge of rotational instability. Moreover, such stars are *not particularly dense* and they are observed *not to shed* their atmospheres. These observed facts, when taken together with the known great number of observed visual binary star systems, show clearly that the theoretical arguments of earlier investigators were based on insufficient consideration of all the facts. It seems certain that forces other than those of gravitation must be important in guiding the course of evolution, and further progress evidently depends upon their careful consideration. What is the nature of these forces? The answer is to be found in the published

[3] Chamberlain, Carnegie Inst. Pub. 107, 169 (1909).

papers of the author which discuss various theoretical aspects of stellar electricity and magnetism and show that the electromagnetic forces acting on the ions of a star's atmosphere determine in an important manner its observed motion and stability. These mechanisms introduce forces that are novel and unfamiliar to astronomers but they turn out to be the precise forces necessary to account for many very puzzling and hitherto unexplained astronomical facts. The atmospheres of all hot stars are known to be almost completely ionized and it is evident that electric and magnetic forces might play a major part in determining their motions and stability if magnetic and electric fields were actually present in the atmosphere.

An early paper considered the motions of ions executing long free paths, under the influence of thermal agitation, in crossed electric and magnetic fields and emphasized the astrophysical importance of these effects. This study opened a field of investigation which has also been fruitful in the hands of several other investigators. It was shown in the first two papers that the impressed electric and magnetic forces cause the ions to move in such a manner that

(1) The electrical conductivity of the region is abnormally low.
(2) The region becomes highly diamagnetic.
(3) Both kinds of ions are swept in the same direction at right angles to both the electric and magnetic fields with the same velocity and this motion constitutes a mass movement of the ionized gas.
(4) An electric current results if the magnetic field is not homogeneous.

We now consider the application of these effects to stellar problems.

Stellar Magnetic Fields.

The sun and the earth are the only astronomical bodies about which we have relatively complete physical information and it is well established that they both have permanent magnetic fields which are quite similar. The sun's magnetic field is much larger than that of the earth and it decreases radially with great rapidity, but its polarity and distribution

at given levels coincide closely with those observed on the earth. A theoretical investigation of the mechanism giving rise to the magnetic field shows that a small initial magnetic field and a radial electric field arising from the gravitational separation of electrical charge, inside the body, is capable of producing current systems quite adequate to produce the observed fields. Thus the magnetic field of the sun probably depends on its internal constitution and has no direct relation to its rotation. Since the sun in other respects is a typical dwarf star we have assumed that all dwarf stars have such fields. Whether this is a legitimate extrapolation, only the future can decide, but it leads to other important conclusions which are in remarkable accord with direct observation.

The thermal motions of the ions in the sun's atmosphere cause them to spiral around the impressed magnetic field in such a way as to make the region diamagnetic. A calculation of the reduction in the permeability of the sun's atmosphere due to this effect, using data that are well known, shows that the effective permeability is distinctly less than unity and perhaps does not exceed 1/2. This low permeability of the surrounding atmosphere restricts the solar magnetic field to a thin layer some hundreds of kilometers deep and distorts it in such a way that the magnetic field is nearly tangential to the surface at all latitudes. Thus since the electric field, if it exists, must be radial, the magnetic and electric fields are nearly perpendicular over the entire sun. The limitation of the magnetic field of the sun is, of course, an outstanding characteristic that has been observed and often remarked.

Magnetic forces are also important in determining the course of rotational evolution for we must note that the ions of the sun's atmosphere execute very long free paths and are constrained to spiral about the impressed magnetic field as a result of their thermal velocity. Not only is a diamagnetic effect produced, but the ion is entrapped by the magnetic field and because the magnetic forces are thousands of times greater than the gravitational forces, the observed motions and stability of stellar atmospheres are determined almost completely by them. Thus if a star rotates faster and faster on its axis until the surface gravitational acceleration becomes zero or even reverses sign, the star will still retain its ionized

atmosphere and it will eventually be able to divide. Therefore, Chamberlain's criticism of the fission theory need no longer concern us for it is contrary to both theory and observation.

Stellar Electric Fields.

In addition to a magnetic field, the earth has an electric field which is radially inward and has its maximum value in regions where the electrical conductivity is a minimum. Moreover, it is known that there is a highly conducting layer at great altitudes which helps to equalize local irregularities of the electric field.

Because the analogy between the magnetic fields of the sun and earth was so striking it occurred to the writer some years ago that a similar correspondence of the electric fields might be expected. Rough calculations showed that the fields in the sun could not be excessively large and therefore their presence could not be detected by means as insensitive as the Stark effect. It may be said, that there is yet no satisfactory quantitative theory of the electric field of the sun or of the earth and we must therefore be content with observational data.

We can calculate with a fair degree of approximation the electrical conductivity of the sun's atmosphere and we find that the distribution of conductivity is not unlike that of the earth except, of course, it is greater because of the intense ionization. At levels well below the photosphere where the ion pressure is greater than an atmosphere, the electrical conductivity is very large. In other regions of the sun where the ion pressure is less than half an atmosphere the electrical conductivity is very low, because in these layers the magnetic field entraps the electrons and the conductivity is due primarily to heavy ions, which themselves advance across the magnetic field with some difficulty. At still higher atmospheric levels near the top of the chromosphere the value of the magnetic field drops and electrons again contribute to the conductivity. It is estimated that the electrical conductivity of the upper chromosphere and corona is thousands of times that in a typical region of the reversing layer. We are dependent on an entirely different mechanism to prove that these

highly conducting regions can support an appreciable electric field, and we now turn to its consideration.

Electromagnetic Winds.

Perhaps the most important result of the combined presence of crossed electric and magnetic fields in the sun's atmosphere would be a mass motion imposed on the ions that constitute it. The velocity of this mass motion we have shown is independent of the mass, sign or magnitude of the charged particle and depends only on the ratio of the magnitude of the electric field to that of the magnetic field. Mass motions of the sun's atmosphere would be more readily observed than the corresponding electrical and magnetic quantities so that in an early paper entitled "On the Anomalous Rotation of the Sun," we determined the magnitude and radial distribution of the electric field from the observed motions of the atmosphere. In a later paper we calculated the electric fields from certain spectroscopic data and found values in good agreement with the earlier values.

Observation shows that the sun's magnetic poles do not coincide with the solar axis but rotate about it once in 31.8 days. Because the internal viscous forces arising from radiation and electromagnetic effects are large, it seems correct to assume that the sun is a semi-rigid body rotating much like the earth and carrying the magnetic poles around with it once a revolution. Adopting this reasonable hypothesis it follows that the sun's atmosphere *rotates faster* than the sun proper, for observation shows the equator apparently rotates once in 25 days and this period increases with increasing latitude.

Evidently no simple mechanical motion of the atmosphere can account for this phenomenon; for the initial momentum of the atmosphere is small and it would soon be transferred to the sun proper by the interchange of momentum between the regions.

The mass motion of the ionized atmosphere resulting from crossed electric and mangetic fields, which we will refer to as an "electromagnetic wind," offers a beautiful explanation of the observed atmospheric motions if the sun actually has an electric field that is radially inward (same direction as the observed terrestrial electric field), amounts to 0.013 volt/cm. in a

typical region of the reversing layer and decreases with increasing altitude at about the same rate as the magnetic field is observed to decrease. In the paper already referred to it was shown that the electromagnetic winds would change with latitude, altitude, and with changing solar activity in just the right way to account for all the major features of the anomalous rotation of the sun. This agreement with observation seems to establish a presumption in favor of the existence of a solar electric field and the extension of the idea to include all stars is possibly legitimate.

ROTATIONAL EVOLUTION.

Origin of Stellar Rotation.

The foregoing discussion of the rotation of the solar atmosphere has been given in order to lead up to one of the most important questions of astrophysics. Why is rotation a common property of all heavenly bodies and how did the rotation originate? It should be clear that the rotation of the sun's atmosphere faster than the sun's surface will result in a transfer of momentum from the atmosphere to the sun proper by the viscous forces. The momentum of the atmosphere is constantly replenished by the electrical forces, and that transferred to the sun is stored and constantly increased. Rough calculations establish the order of magnitude of the transferred momentum and it turns out to be just sufficient to cause a hot star to become rotationally unstable if it acts for a period of time somewhat less than the mean indicated age of all stars. A casual examination of the phenomena might suggest that a compensating momentum will be added to the magnetic field; but this is not the case, for an axial magnetic field is not a fixed reference system and cannot add to or subtract energy from the moving ions, because the magnetic force is always perpendicular to the motion. The principles of unipolar induction make it seem probable that the only result of the magnetic field is to change the direction of the ions in such a way that the radial momentum of the ions is converted into axial momentum. Thus, angular momentum is not conserved in an evolving dwarf star as Moulton has supposed, but is constantly generated and transformed by electromagnetic means. We believe therefore that in the foregoing mechanism we have

found the reason why stars rotate and simultaneously discovered the mechanisms that guide the course of evolution in a star.

We may suppose, in view of the foregoing, that a massive star under normal conditions will have very high velocity electromagnetic winds blowing in its atmosphere in such a direction that they will slowly increase its angular velocity until it spins on its axis very rapidly, just as many early type stars are actually observed to do. The speed increases and if the mass of the star is concentrated somewhat toward the center we may suppose that the surface acceleration actually reverses before the star finally becomes rotationally unstable and flies apart.

Radiation Reaction Forces.

According to Darwin's calculations a rotationally unstable liquid star breaks up into two sections of substantially equal mass. The parent star is radially symmetrical but the resulting components must necessarily be unsymmetrical, for that hemisphere of each component born from deep inside the parent star will be at a far higher mean temperature than the hemisphere born from the surface layers. The asymmetry of temperature is especially pronounced at the surface, for one face of a component star is hardly disturbed by the cataclysm while the other, originally deep in the interior of the parent star, suddenly becomes the surface. That the initial surface temperature of the inner face must be very high follows at once from the fact that the act of fission is cataclysmic. It seems legitimate to assume that the initial temperatures of the inner faces are at an appreciable fraction of the original central temperature of the parent star. Obviously these surface temperatures are not maintained for long because radiation carries off the energy very rapidly as soon as the hot face is exposed to free space. On the other hand, a comparatively small fractional drop in the surface temperature of the hot face will set up large internal temperature gradients and energy will be rapidly transmitted to the surface either by radiation or by conduction. If the temperatures are unexpectedly high the process could, perhaps, be more accurately described by saying that the exposure of the hot face will give rise to a "radiation explosion" which is dynamically equiva-

lent to the comparatively slow processes we use in the following calculations.

Internal radiation pressure always acts to make the star unstable, but the asymmetrical loss of matter by radiation or by gaseous ions also produces a reacting force on the star proper, and the reacting momentum is precisely equal and opposite to that carried away by radiation even when the star is isolated. Thus a recently divided component star with one face much hotter than the other behaves in a manner analogous to a skyrocket, and if there are two stars rotating about their center of mass and if the tidal angle is different from zero, the pair behaves like a pinwheel. When the hot face is at a sufficiently high temperature this new mechanism has a profound and immediate effect on the orbit of the pair and may even operate to separate them to infinity. If the thermal asymmetry is not particularly pronounced the phenomena, of course, proceed at a slower rate but in the course of stellar time the asymmetrical loss of mass may greatly modify the original orbit.

We have introduced this new mechanism to add angular momentum and kinetic energy to the star pair at just the time of breakup, for observation shows that all visual binary systems possess much more angular momentum and kinetic energy than could be stored as such in the parent star. The orbits of the resulting star pair evidently will depend in an important manner on the initial surface temperatures, on the tidal angles, and on the speed with which the cataclysm proceeds. As far as is now apparent we may adopt either a cataclysmic evolution of the pair in which the initial state is completed within two or three days or let it proceed over millions of years.

Novæ occasionally appear in the sky and it is suggested that a nova is simply a splitting star. We know that the initial evolution of the nova is completed in a very few days and to be consistent we should perhaps assume that the initial evolution of the binary pair is completed in a day or so. By adopting a reasonable value for the fractional mass radiated during the transition state and neglecting the inevitable interchange of mass before the two components actually separate, it follows that the surface temperature of the components must approximate 3×10^7 degrees. This is high, to be sure, but is only half the central temperature of the

sun, as calculated by the now conservative star model of Russell and only one-thousandth of the central temperatures of the star models studied by Milne.

The energy added to an isolated component star by the radiation of mass from one face is readily calculated and it is found that if 2/10,000 of its total mass is so radiated, then the star will gain kinetic energy equivalent to that energy necessary to separate two stellar components of the same mass to infinity. Thus if the surface temperature is initially that just indicated both the time and energy scale will be correctly adjusted to permit the stars to form either a visual binary system or by slight readjustments to form two separate and independent stars. Visual binaries are very common and because the energy of a visual configuration and the same two stars separated to infinity is so nearly the same, we must conclude that single isolated stars that have experienced the fission process must be equally common. This is an important conclusion for our sun is fairly well advanced in the course of evolution and it probably has broken up at least once. We assume that such is the case and examine the fission process to see if it could have produced anything like our own solar system.

FORMATION OF THE PLANETS.

Suppose a parent star much like our sun, except more massive, did spin faster and faster on its axis until it rotated about once in six hours. It would break up at this speed if of uniform density and at a somewhat higher speed if its mass were slightly concentrated toward the center. Two components of comparable mass would result which would separate in a manner dependent on their angular momentum and energy. We have seen that the asymmetrical radiation of mass can add both energy and momentum to the pair after division and the variable quantities are sufficiently diversified to permit almost any type of orbit to be generated by the components. We must suppose that in the case of the solar system the added energy was ample to separate the resulting components to infinity.

Tidal Instability.

While the two component stars are very close to each other, the remote and inner surface regions are necessarily in un-

stable equilibrium because, as Roche has shown, no body can be in stable equilibrium if that body is within 2 1/2 radii of the tide raising star. We can perhaps see that this is true by considering two stars that rotate in circles about each other. The separation of the centers of gravity of the stars evidently depends on the angular velocity of revolution of the pair, and when dynamical equilibrium is reached, the gravitational and centrifugal forces just balance. Small masses radially outside the center mass of each star will rotate too fast to be in equilibrium of themselves while points inside will not rotate fast enough. Gravitational forces will keep the small masses in equilibrium only up to a certain limit and it should be clear that the chance of disintegration will increase with increasing orbital angular velocity and increasing radial separation from the center of gravity of the star. Precise calculation shows that the critical angular velocity at which the centrifugal force exceeds the gravitational force is reached when a body approaches to within about 2 1/2 radii of the tide raising body. This is known as the Roche tidal limit. It should be noted that instability of this type is greater in those regions of the body which are remote from its own center of mass and if the body breaks up the masses lost will be small compared to the mass of the body itself. Evidently disintegration may result from a deficiency of velocity as well as an excess.

Thus when our parent star splits and the two component stars are very near to each other, and hence inside the Roche limit, the outermost and innermost surfaces disintegrate and masses are detached which are small compared to the masses of the primary. *These small masses are the planets.* Now before the planets can recede from the companion stars, they too break up as a result of centrifugal instability inside the Roche limit and the planetary satellites are formed. Again the ratio of the masses disintegrated to that of the body proper, is small.

Tidal Couples.

During the process of break up tides and tidal couples are, of course, active and play an important part in guiding the course of events. It is quite impossible to calculate precisely the angular accelerations imposed on the mass components due to tidal couples but the change in angular velocity can be

roughly estimated by assuming several successive configurations which are in quasi-equilibrium. These calculations indicate that the tidal couples are sufficient to cause the massive component stars to separate with their hot faces always oriented toward each other. Therefore, by the time that the two components have receded to positions of equilibrium outside the Roche limit their original angular momentum of spin is converted almost entirely into orbital momentum and the spin period of each component has increased by many days. *It is because of these tidal couples that the sun now rotates so slowly.* We must admit that this mechanism takes place in all dividing stars, for astronomers agree that the periods of rotation and revolution of spectroscropic binaries are identical.

According to our account of the formation of the solar system the planets initially rotated with a period approximating that of the critical period of the parent sun, or six hours. Tidal couples just after birth would increase the period but on account of their smaller size the planets accommodated their figure more rapidly to the impressed system of forces than the massive components and therefore largely escaped the effects of angular accelerations due to body tides. We find the larger planets now rotating on their axes about once in 10 hours, indicating that tidal couples played only a minor rôle in the birth process.

The Satellite Systems.

The earth's satellite, the moon, was originally a part of the planet and its present store of angular momentum was in the earth. The earth therefore rotated initially once in 4.1 hours instead of once in 24 hours. Moreover, the critical period of rotation at which it would break up was very close to this or 3.3 hours. Thus initially the earth when it was inside the Roche limit of the sun, was nearly unstable rotationally and a break up which shared the properties of both tidal and rotational instability was to be expected. Thus the mass of the satellite thrown off should have been relatively large. This is just what happened: for the moon is observed to have a mass 1/80th that of the earth and is the largest satellite compared to its primary, in the solar system.

After the moon was actually detached from the earth, tidal couples rapidly transferred the moon's angular momentum of spin to that of orbital momentum, and the earth is still losing and transferring its angular momentum by the same means. This process adequately accounts for the present position of the moon and the fact that its period of axial rotation corresponds to its revolution.

Mars beautifully supports our conclusions regarding the moon, for Mars is small, and like the earth, must have escaped the effects of the tidal couples. Therefore its initial angular velocity must have been nearly the same as the earth even though it now rotates very slowly. This conclusion is further supported by the period of revolution of Phobos which makes a complete circuit in 7 1/2 hours. It seems clear that Mars also once had a massive satellite that was produced by a combination of tidal and rotational instability and that this massive satellite was lost or perhaps it broke up and formed the asteroids. Thus the earth and Mars must have experienced largely the same development.

The satellite systems of the major planets resulted primarily from tidal instability and their masses are consequently small relative to the primary. Data regarding Venus and Mercury are not well determined but they are so close to the sun that tidal development since their generation probably has been important.

The Orbits.

We must now suggest the mechanism by which the planets were dispersed over a large area while the planetary satellite systems are relatively condensed. We might suppose that the parent star was once 50 or 100 times as large as it is now but this seems to be unnecessary and we need only follow out logically the consequence of the radiation of mass by the hot faces of the lost solar component. Both companions have kinetic energy and angular momentum added to them by radiation reaction forces. The exposed areas and effective surface temperatures of both hot faces initially are nearly the same so that the rate of loss of momentum by radiation is the same for each. Thus, at first, the accelerations of the stars are nearly inversely proportional to their respective masses and the stars separate from each other with constantly in-

creasing velocity. The companion sun starts out with its family of satellites, in an orbit about the sun, but it is constantly accelerated and calculations show that this acceleration may quite reasonably exceed its gravitational acceleration for the planets. In favorable parts of the planetary orbits the companion star, due to its increasing velocity loses gravitational control of the planet while the sun proper, because of its smaller non-central acceleration and greater mass, retains control and the planet finally revolves about it. The net result of the process is that a number of planets are strung out through space, perhaps to infinity; they have considerable angular momentum about the sun, and are necessarily many solar radii distant from it.

We may therefore think of the solar system as being almost completely formed when it was still condensed into a relatively small space where tidal forces were important and may attribute its present open structure to the same mechanism that removed the companion star to infinity. While in this condensed state we may suppose that certain satellites transferred to other primaries and therefore could have described remote and retrograde orbits. The planetary satellite systems are relatively condensed because their positions were almost entirely determined by their original angular momentum. Thus the net result of our rotational cataclysm is a very disperse system of two slowly spinning stars and a system of planets and planetary satellites. All bodies of the system revolve in the same direction and in the same plane and spin on their axes with an angular velocity comparable to that of the parent star. One star is eventually lost to infinity and the solar system, as we know it, results. It hardly need be said that the orbits of the planets after they are detached must be very complicated for we have a three body gravitational problem and a superposed system of non-central forces. The final orbits can only be worked out by rough graphical methods after making suitable assumptions for the initial conditions. The variables in the problem susceptible of adjustment to secure the proper initial conditions seem sufficient to allow the resulting planetary orbits to be circular, but the laborious task of calculating them has not yet been carried through. The assumption of a resisting

medium would definitely account for the observed circular orbits, but this assumption is highly unsatisfactory and probably not necessary. It is hoped that the matter can be settled in later investigations.

Remarks.

Our new theory of the origin of the solar system is far more detailed than any of the earlier theories and will therefore be subject to a more searching criticism. It has successfully met many critical tests and seems capable of extension to meet many more. Recent calculations which give the theory further quantitative support, show that it will be necessary to take account of the concentration of matter toward the center of both the sun and the planets and also their tidal deformation. This is, perhaps, just what we should expect although it makes the solution of our problem very difficult. The main contributions to the subject reside in the recognition (1) of certain new electromagnetic effects and their importance in stellar electricity and magnetism, (2) the effects of asymmetrical radiation of mass, (3) of the important part a second component star would play in increasing the period of rotation of the sun and carrying off any excess angular momentum and (4) finally, that the formation of planetary systems was but one step in the march of evolution in binary star systems.

If we have correctly traced the course of events and our solar system is in fact the result of a great rotational cataclysm that overtook the parent sun as a necessary consequence of the electromagnetic motions of its atmosphere; the solar system and the inhabitants of the system must indeed be part of a great evolutionary plan. Millions of binary star systems exist in the universe and the fission process must be very common. Planetary systems must be equally as numerous and we must conclude that conditions on many of them are similar to those existing on the earth.

Much labor and time must be spent before our account of the formation can be checked in all its details and a decision made as to its truth but we have closely adhered throughout the theory to observed facts whenever they were available and supported each step by rough calculations. It seems quite clear that our mechanism is real and that the solar system did *not* originate as the result of a highly improbable acci-

dent as earlier investigators would have us believe, but came into being as the result of an orderly evolutionary process that we have reason to believe is quite common in the Universe.

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Installing Decorative Tiling Yourself.—*Ceramic Industry* for Feb. 1932 describes a much simpler and more rapid method of laying tiles. The tiles are laid onto a metal lath backing which consists of a punched sheet of metal having special mechanically formed fingers or grippers projecting at right angles. The clips not only securely hold the tiles against the lath but also automatically bring them into correct alignment as they are snapped into place. Any home owner may install his own tile decorations with a minimum of inconvenience and trouble. The lath may be purchased with the tile and is fastened on over the plaster making removal of the latter unnecessary.

T. K. C.

Bricks That Float.—(*Ind. and Eng. Chem.*, Feb. 1932.) In his acceptance speech at the time DR. C. F. BURGESS was presented with the Perkin Medal for 1932 he described a building brick just one-fifth the weight of an ordinary brick. Prepared from a certain clay, this constructional element will float in water and continue to do so even after a year's immersion. The brick possesses good heat-insulating qualities, is porous yet water resistant and of such strength it will support a column of the brick equal to five times the height of the Empire State Building. It is estimated that two of these bricks can be laid with an expenditure of physical effort equal to that now required for the regular kind.

T. K. C.

Special Fermentation of Corn Meal.—(*Ind. and Eng. Chem.*, Feb. 1932.) W. H. PETERSON AND E. B. FRED have employed a particular type of bacteria which bears the imposing name: *Clostridium arctobutylicum*. When this organism is added to corn meal mash a vigorous fermentation rapidly sets in. The major products of this fermentation are the two gases—hydrogen and carbon monoxide; the solvents—acetone, butyl alcohol and ethyl alcohol; and residual acids—mainly acetic and butyric. Using a 6 per cent. mash, the total volume of gas produced was almost 20 times the volume of the mash. Forty per cent. was hydrogen, the balance, carbon dioxide. At the end of the fermentation period about 1.3 per cent. of the liquid is total solvents which on the average consist of 9 per cent. ethyl alcohol, 31 per cent. acetone and 60 per cent. butyl alcohol.

T. K. C.

THE HATCHET PLANIMETER.

BY

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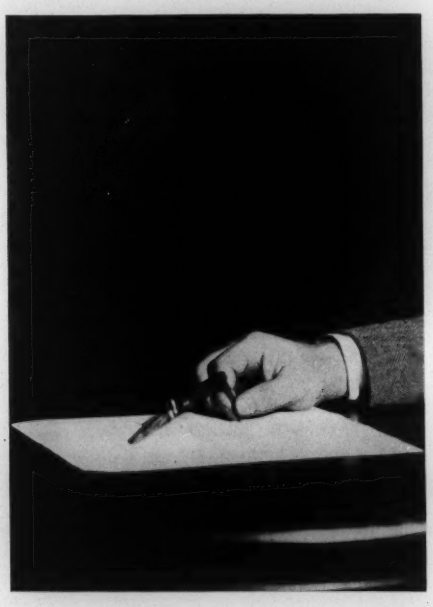
It frequently happens that some one is doing a little work at home or in the field where draughting tools are not at hand but where a knife is almost always available. It is not in design work alone that planimeters are used. Whenever an indicator card is taken to determine the power output of an engine its average height can be found only after the area of the figure is known. Again the core loss of a magnetic circuit is obtained from the area of the hysteresis loop. There are a number of well known ways in which the work can be done, such for instance as replotting the curve on graph paper and counting the squares inclosed. This, as are the other ways of getting the result, is very laborious and unnecessary trouble.

With the instrument at hand a planimeter would usually be preferable, or possibly an integraph. Lacking these one can use his penknife and get the result as accurately by exercising care as with the more elaborate instruments. First it is necessary that the knife have one blade opened fully at one end and at the other something which will serve as a pointer to be opened half way. The latter may be a blade, a nail file, or a pipe cleaner as on many knives. This half opened blade we will call the pointer. It is supposed that the figure whose area is desired is drawn on a sheet of paper. Look the drawing over and estimate the center of the figure. It is not necessary that this be anything more than a rough estimate. From this center draw a line to the edge of the figure. (A light pencil line that can be erased is sufficient.) Taking the knife in the right hand hold it with the end of the pointer directly over the center of the figure and with the sharp edge of the other blade resting lightly on any convenient paper, either the same piece that the drawing is on or another piece put in a suitable place for the purpose. With the left

hand press the blade into the paper enough to leave a legible mark. It is essential that the blade be held lightly as shown in the photograph. With the thumb and index finger of the right hand hold the lower end of the pointer very tenderly so as not to tend in any way to skid the sharp edge of the blade across the paper. The upper end of the pointer and possibly part of the handle may rest gently against the upper part of



the index finger. This matter of holding the knife correctly is the only difficult part of the operation and may be mastered in a few careful trials so that it becomes natural and easy. The pointer is then moved along the line to the edge of the figure, thence along the boundary of the area to be measured and back to the center, the starting place, along the guide line. The blade of the knife is again firmly pressed into the paper

to make a second mark. The motion of the knife, pointer and blade, is somewhat like that of a cat being chased by a dog which always heads straight for the cat but never succeeds in getting any closer.

It is then necessary to measure the distance between the two imprints of the knife and also the distance from the center of the figure, that is from the starting place of the pointer, to either of the two imprints. It now remains only to multiply these two distances together to get the required area. If the distances are measured in inches then the area will be expressed in square inches, if the centimeter scale was used then the area will be given in square centimeters, and so for any system of units.

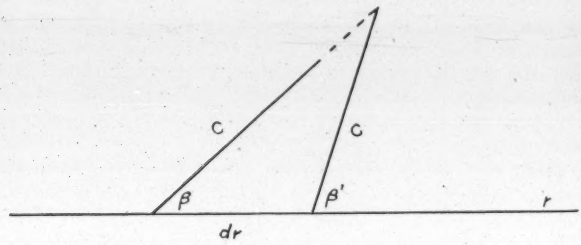
There are certain precautions to be taken and limits to be considered when using the knife in this way that it is well to point out. It is best that the greatest distance from the center of the figure to the most distant part of the perimeter be less than one eighth of the length of the knife and one blade. If it is otherwise, then the area may be approximated twice by this method, first encircling the area in one direction with the pointer and the second time encircling it in the other direction. These two results should be averaged for the most probable value of the area. In any case it is best not to have the greatest length of the figure more than the length of the knife and one blade. Following these directions anyone can do with a knife and scale all the work that can be done with the most expensive planimeter and in very little more time. In the case of a very large figure the area may be divided into smaller sections or a larger knife be used. In the appendix which follows the derivation of the equations from elementry principles is given so that the reason for these instructions is easily seen.

APPENDIX.

This use of a penknife is known as the hatchet planimeter, and though it was devised long ago it has not become generally known because of the complicated theory and the many commercial types of planimeter which are simpler. For the benefit of those who are interested in knowing how and why it works the following mathematical proof is given.

Because it will be needed in the proof we will begin by deriving the equation of the curve of pursuit. Consider in Fig. 1 the heavy line as a knife moved a slight distance along the line r so that the blade moves along the dotted line of the figure. Let c be the length of the knife and let dr be the distance moved by the pointer. Let the angles β and β' be as shown.

FIG. 1.



Then since dr is small the angle opposite is $d\beta$.

By the law of sines

$$\frac{d\beta}{\sin \beta} = \frac{dr}{c};$$

integrating,

$$\log \tan \frac{\beta}{2} = \frac{r}{c} + \log K,$$

or

$$\tan \frac{\beta}{2} = e^{r/c} K;$$

determining the constant

$$\tan \frac{\beta}{2} = e^{r/c} \tan \frac{\beta'}{2}, \qquad (1)$$

which is the required equation.

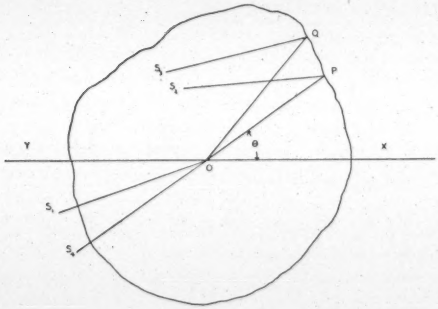
In Fig. 2 let o be the point from which the knife pointer is to be started. Let S_1 be the first position of the knife and S_4 the last. Suppose that the knife is moved from the first

position to a point P on the curve along a straight line making an angle θ with the axis. Then let it be moved a slight amount along the curve to a point Q. The knife will take up positions as shown in the figure. We let

$$XOP = \theta,$$
$$XOQ = \theta + d\theta,$$
$$OPQ = \psi,$$
$$YOS_1 = \phi,$$

inclination S_2P to $OX = \phi'$,
" S_3Q to $OX = \phi' + d\phi'$,
" S_4O to $OX = \phi + d\phi$.

FIG. 2.



Then we have, making use of the curve of pursuit,

$$\tan\frac{\theta - \phi'}{2} = e^{-(r/c)} \tan\frac{\theta - \phi}{2} \qquad (2)$$

and

$$\tan\frac{\theta + d\theta - \phi' - d\phi'}{2} = e^{-(r+dr)1/c} \tan\frac{\theta + d\theta - \phi - d\phi}{2}.$$

Differentiating this expression

$$\frac{d\theta - d\phi'}{\sin(\theta - \phi')} = -\frac{dr}{c} + \frac{d\theta - d\phi}{\sin(\theta - \phi)}. \qquad (3)$$

Then the angle which the arc makes with the rod is $\psi - \theta + \phi'$ at P and it is $\psi - \theta + \phi' + d\phi'$ at Q.
Therefore

$$\frac{d\phi'}{\sin(\psi - \theta + \phi')} = \frac{ds}{c},$$

or, what is the same thing,

$$cd\phi' = \{\sin\psi\cos(\theta - \phi') - \cos\psi\sin(\theta - \phi')\}ds,$$

after further combining

$$cd\phi' = rd\theta\cos(\theta - \phi') - dr\sin(\theta - \phi') \qquad (4)$$

Then we put equation 4 in equation 3 and obtain

$$\frac{cd\theta - rd\theta\cos(\theta - \phi')}{(\theta - \phi')} - dr = -dr + \frac{c(d\theta - d\phi)}{\sin(\theta - \phi)}$$

making use of equation 2

$$\frac{d\theta - d\phi}{\sin(\theta - \phi)} = \frac{d\theta}{2}\left(1 - \frac{r}{c}\right)e^{r/c}\cot\frac{\theta - \phi}{2} + \frac{d\theta}{2}\left(1 + \frac{r}{c}\right)e^{-(r/c)}\tan\frac{\theta - \phi}{2};$$

clearing fractions

$$d\theta - d\phi = \left[\left(1 - \frac{r}{c}\right)e^{r/c}\cos^2\frac{\theta - \phi}{2} + \left(1 + \frac{r}{c}\right)e^{-(r/c)}\sin^2\frac{\theta - \phi}{2}\right]d\theta$$

and, making substitutions for the double angle,

$$d\theta - d\phi = \frac{1}{2}\left[\left(1 - \frac{r}{c}\right)e^{r/c} + \left(1 + \frac{r}{c}\right)e^{-(r/c)}\right]d\theta - \frac{1}{2}\left[\left(1 + \frac{r}{c}\right)e^{-(r/c)} - \left(1 - \frac{r}{c}\right)e^{r/c}\right]d\theta\cos(\theta - \phi)$$

The two parts are each able to be expressed in series thus

$$d\theta - d\phi = \left(1 - \frac{r^2}{2c^2} - \frac{r^4}{8c^4} - \frac{r^6}{144c^6} - - -\right)d\theta - \left(\frac{r^3}{3c^3} + \frac{r^5}{30c^5} + + +\right)\cos(\theta - \phi)\,d\theta.$$

Integrating termwise

$$c^2\Phi = A + \frac{1}{8c^2}\int_0^{2\pi} r^4 d\theta + \frac{1}{144c^4}\int_0^{2\pi} r^6 d\theta + + +$$
$$+ \int_0^{2\pi} \left(\frac{r^3}{3c} + \frac{r^5}{30c^3} + + +\right) \cos(\theta - \phi)\, d\theta.$$

This last expression is the required result. We notice that the left hand side of the equation is the square of the length of the knife multiplied by the angle it moved through in tracing the figure. If the angle is small as it will be when r is one quarter or less, then the chord is nearly equal to the arc and the length of the knife can be multiplied by the distance from first position to last position of the blade. In some of the commercial forms of this instrument there is a scale engraved on one side to read areas directly and in this case the edge is curved to measure the arc. The first term of the right hand side of the equation is the value of the area sought. It is increased by the many terms which follow. If the pointer is started from the center of the figure as was suggested above, then the value of all these remaining terms will be less than for any other starting point. Then if the greatest length of the figure is not over about one fourth of the length of the knife all these terms will be negligible. In case of a larger figure note that the second series is composed of odd terms only. Therefore in tracing the figure in one direction they add to the sum but going in the other direction will subtract. So that averaging two readings obtained by running the pointer in alternate directions will remove the effect of these terms entirely. The remaining terms would be certainly less than

$$\frac{2\pi r^4}{8c^4} + \frac{2\pi r^6}{144c^6} + + +$$

which, if the greatest length of the figure equals the length of the knife, an extreme case, means an error of about six per cent.

Measuring a few areas with a penknife (such as indicator cards) and then with a planimeter will show that the hatchet planimeter is as accurate as the graduations of the best scales will permit of reading.

Shredded Leather.—Do you know a good use for shredded leather? C. D. INGERSOLL in *Chem. and Met.* for Feb. 1932 discusses the possibilities for utilizing waste scrap leather. In years past this scrap leather was used for making prussiate of potash by lixiviating it along with old shoes wool waste and other protein refuse with potash in the presence of iron. Another use has been the making of fertilizer. It is said that only vegetable-tanned leather is suitable, chrome tannages being injurious to the plants. As a last resort, the accumulated scrap may be disposed of as boiler fuel. The quantities of scrap leather have been on the increase due to the increase in size of manufacturing units and the development of new machinery. There is a greater wastage of leather but this is more than compensated by the saving in time and labor.

Leather is fibrous in nature and when shredded it is in an ideal state that permits its refabrication into many new forms. The shreds possess great matting ability and when strongly compressed will retain their new shape without the aid of a binder or adhesive. The utilization of shredded leather is merely in a state of development but already serious attention has been paid to its possibilities for making wallboard, low temperature insulating materials, flooring and even paper.

T. K. C.

Adding Sugar to Concrete.—What is more, it looks as if an era of perfumed or pleasant smelling lacquers was about to begin. At the spring meeting of the American Chemical Society at New Orleans, Mar. 29, 1932, Drs. Gerald J. Cox and John Metschl, of Mellon Institute of Industrial Research, outlined the results of their intensive researches upon cane sugar as an industrial raw material. By treating cane sugar with strong acetic acid or its derivatives they obtained a substance having the cryptogramic name: sucrose octaäcetate. This product has been found valuable in certain types of lacquers and adhesives and in the fabrication of paper.

When the sugar is treated with acid at high temperatures and the resulting levulinic acid combined with certain alcohols, fragrant esters having useful solvent powers are obtained.

The most outstanding piece of study probably was that on the practice of adding cane sugar to a lime-sand mortar. If sugar equal to as little as 6 per cent. the weight of the quicklime is included in the mortar, the tensile strength is increased about 60 per cent.

T. K. C.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

VOLUME CHANGES IN CAST IRON DURING CASTING.

The bureau, in coöperation with the American Foundrymen's Association, has recently made a study of methods for determining volume changes in metals during casting. A knowledge of the magnitude of these volume changes is considered essential to good foundry practice in order to produce sound casting economically.

A method was developed, applicable to cast irons as well as to non-ferrous metals, which permits determination of the shrinkage undergone by the metal from a temperature in the liquid state to room temperature.

The application of this method under actual foundry conditions is too involved and time-consuming. Consequently, an indirect method, based upon data obtained on 12 cast irons, has been devised by means of which it is believed the volume changes occurring in cast irons during casting can be quickly determined in the foundry and with sufficient accuracy for all practical purposes.

The total amount of impurities and the linear contraction of the cast iron in cooling from the freezing temperature to room temperature are all that need be determined in the foundry.

The volume changes that take place while cooling in the liquid state, during solidification, and upon further cooling to room temperature are calculated from these data and from three charts, the derivation of which was described in a recent Bureau of Standards' publication.

MECHANICAL PROPERTIES OF WHITE-METAL BEARING ALLOYS AT DIFFERENT TEMPERATURES.

The usual white-metal bearing alloys require tin or antimony or both as essential constituents. Both tin and antimony are so-called "strategic" metals and the potential

* Communicated by the Director.

military demands for these metals are considerable. These facts were responsible for the sponsoring by the War Department of recent studies at the bureau aimed towards the reduction or possible elimination of the amounts of tin and antimony needed for bearings.

One phase of this work was a study of the wear resistance and other mechanical properties of ten white-metal bearing alloys. The alloys tested included two tin-base and seven lead-base alloys and one alloy of cadmium and zinc.

Each of the properties, with the exception of wear, was determined at several temperatures ranging from 20° to 200° C. (68°–390° F.), since it is in reality the properties at the higher temperatures that play the major part in determining the success or failure of a bearing metal under service conditions. Resistance to wear was determined only at 20° C. No one of the alloys considered was found to excell in all of the mechanical properties studied. Thus, the tin-base alloys showed higher resistance to wear and in most cases had higher Izod impact values, at each temperature of test, than the lead-base alloys, but in most cases, showed lower resistance to pounding than the lead-base and cadmium-zinc alloys. The hardness numbers and compressive properties of the tin-base alloys were found to be lower than those for the alkaline-metal hardened lead and the cadmium-zinc alloys. The alkaline metals used for hardening lead were calcium and barium. The mechanical properties of the lead-antimony-tin alloys, in most cases, were higher as the tin content was increased.

Crankshaft bearings of four compositions were prepared for service tests in U. S. Army Class B. trucks. These compositions consisted of two tin-base and two lead-base alloys. The results of these tests indicated that the tin-base alloys were superior in their wear resistance to the lead-base alloys. These results were consistent with those obtained on wear in the laboratory tests.

FACTORS AFFECTING THE PHYSICAL PROPERTIES OF CAST RED BRASS.

In 1929 when the special committee of the American Society for Testing Materials on promotion of general use of

specifications for copper alloys in ingot form made a survey of the industrial field, it was found that 600 copper-base alloy-compositions were then in use that might be grouped into 20 classes. Simplification in industry inspired the hope that eventually each class might be represented by one composition.

The Non-Ferrous Ingot Metal Institute agreed to sponsor an investigation at the bureau under the research associate plan. The purpose of the investigation was to obtain data upon which to base further work of bringing about agreement upon an optimum number of typical compositions of copper-base ingot metal and to develop equitable standard specifications for the different classes.

The advisory committee of the Institute suggested that as red brass of the nominal composition of 85 per cent. copper and 5 per cent. each of zinc, tin and lead, is one of the most widely used copper base commercial alloys that it should be the first alloy investigated. As it was recognized that no particular type of test bar is now accepted as standard by industry, several distinct types were selected to be compared. The effect of pouring temperature and the influence of the use of virgin metal or remelted metal were other factors to be studied.

The tensile strength, Brinell hardness, electrical resistivity, and density were determined for various types of test bars cast at temperatures ranging from 1,900 to 2,300° F. The maximum values were obtained for the test bars cut from the chill ingot, and pouring temperature had little influence on these results. Somewhat lower values were obtained for the test bar by the immersion in the molten metal of a graphite shell. Lower values were obtained for the sand cast test bars. For the latter it was found that a pouring temperature above 2,200° F. had a pronounced influence on the physical properties.

A study of the metallographic structure of the test bars poured at high temperatures indicated that the marked columnar structure formed under such conditions is accompanied by inferior physical properties.

Microscopic examination of the same bars showed markings due to strain or deformation in the sand cast bars that

were absent in the bar from the immersion crucible. To this was attributed the difference in physical properties at the high temperatures.

The alloy made from remelted metal was found to be somewhat more fluid than from virgin metal cast under the same conditions. The shrinkage of the alloy from the highest pouring temperature to room temperature was determined. It was noted that the alloy expands slightly immediately after solidification after which it contracts at a uniform rate to room temperature.

CORRELATION OF SOME MECHANICAL AND MAGNETIC PROPERTIES OF 1.21 PER CENT. CARBON TOOL STEEL.

This investigation was undertaken by the Cleveland Twist Drill Co. in coöperation with the Bureau of Standards, with the idea of minimizing, so far as possible, variables due to complex composition, and difficulties heretofore encountered in the mechanical testing of hardened steel. The material chosen was a simple carbon tool steel and the tests followed a mechanical method which has proved especially suitable for this class of material. In this way, it was hoped that some clue might be obtained as to the fundamental relationships between the magnetic and mechanical properties.

Magnetic and mechanical tests were made on a series of specimens subjected to various heat treatments intended to cover the range commonly regarded as useful for this steel, with some overlapping beyond the regions of usefulness.

An important conclusion drawn from the results is that each property determined has its own individuality, distinct from that of the other properties. Relationships between the several properties are not always obvious, and when they do appear to exist it may be for only a limited range of heat treatments. This behavior indicates that the changes taking place in the constitution of the steel during the heat treatments examined are very complex in their nature.

It should not be concluded that magnetic analysis is of no value, but only that it should be applied with a full knowledge of the limitations of the method and within the range in which correspondence is known to exist.

The complete report of this work will be presented in a paper by J. V. Emmons of the Cleveland Twist Drill Co. and R. L. Sanford of the Bureau of Standards, at the June meeting of the American Society for Testing Materials.

GRAPHICAL DETERMINATION OF POLAR PATTERNS OF DIRECTIONAL ANTENNA SYSTEMS.

In Research Paper No. 435, which will be published in the May number of the *Bureau of Standards Journal of Research*, graphical methods are applied to the determination of directive patterns of antenna arrays which are made up of half-wave or doublet elements. The elements are assumed to be parallel to each other with their mid-points lying in a common plane. This makes it possible to consider them as point sources lying in that plane, provided that in planes parallel to the elements, the directive results so obtained are modified by the cosine law.

The array is drawn to a convenient wave-length scale so that retardations or path differences in any direction from the array may be easily determined for each element. Then at a distant point P the effect of the radiated energy from each element is represented as a vector whose magnitude is a function of the current in its corresponding element, and whose phase angle is determined by the sum of the path difference expressed in degrees and the phase angle of the current in the element. The resultant of this vector diagram is the relative magnitude of the radiation in the direction of the point for which the diagram was drawn. From a number of such diagrams taken for points in different directions and equidistant from the array, the radiation characteristic may be plotted either in polar or Cartesian coördinates.

In order to facilitate the construction of the vector diagrams a special protractor was developed, carrying the scales for the conversion of path differences to phase angles, as well as a circular protractor, one half of which is used for finding the retardation phase angles determined by conversion scales, and the other half for the inclusion of phase differences between the currents in the antennas of the array.

As illustrations of the method, detailed descriptions are given of the steps necessary in determining the patterns of two simple arrays, one a broadside array and the other an end-on array, each comprising two antennas.

By a very simple extension of the method, the directive patterns of groups of antennas may be combined, thus simplifying materially the labor involved in the constructions for a large array. This method may also be applied to an array and its image in the earth. A graphical multiplying chart simplifies the calculation of the image currents. By means of another similar chart the directive effect of a single half-wave antenna may be included in the construction to give the directional characteristics of an array in a plane containing the antennas.

LINEAR THERMAL EXPANSION OF MUSCOVITE MICA.

The total linear thermal expansion of preheated muscovite mica from room temperature to 900° C., the maximum temperature reached, was found to be 0.73 per cent., resulting in a coefficient of 8.3×10^{-6}. The rate of expansion was unusually uniform throughout the entire range. In order to obtain a specimen for this study it was necessary to preheat the mica to approximately 1,225° C. The light, flaky appearance of mica was no longer evident after this treatment. The P. C. E. (softening point) also made on the preheated material, was 14, equivalent under the conditions of the test, to 1,400° C. Petrographic examination showed the original material to be almost entirely free from impurities.

STATICAL HYSTERESIS AND FLEXURAL STRESS IN A FREELY-VIBRATING U BAR.

To be of use in instruments, elastic elements such as springs and diaphragms should be perfectly elastic; that is, a given loading should give a constant value of the deformation under the ordinary conditions of use. However, the deformation varies with change in temperature of the spring, the rate at which the load is applied, the length of time of its application, and the previous conditions of load and time to which the elastic body has been subjected. The effects

not depending upon temperature are sometimes called elastic defects. One of these defects, all of which are of importance to instrument designers, is the subject of Research Paper No. 443 which will be published in the May number of the *Bureau of Standards Journal of Research.*

In general, the cyclic deformation of an elastic body is associated with an appreciable loss of energy. If this energy loss is independent of the time taken in making the load cycle, it is defined as being due entirely to statical hysteresis. One of the methods used in the study of this phenomena, the statical method, consists in subjecting the deformable body, for example, a clamped bar, to a load cycle in which the load is slowly varied, and noting the hysteresis or the excess of the deformation for the decreasing load over that for the increasing load. This method, however, is time consuming and requires extreme care to secure sufficient accuracy. Another, is the dynamical method which consists of observing the rate of dying down of the free vibration of the body. This method is quicker and easier and is therefore preferable, if it can be shown that the results obtained by it are equivalent to those obtained in the first method.

To investigate the reliability of the dynamic method the hysteresis of an Armco iron U bar was determined experimentally by both methods. The experiments by the statical method consisted of two series: In one, the load range was kept constant, and the effective length of the bar varied; in the other, the effective length was kept constant and the load range varied. In the dynamical method the manner of supporting the fork was also varied since this was expected to influence the results. The results of the experiments showed that within the limits of accuracy of the approximate theory used, both methods gave equivalent results.

For stresses above a certain small threshold value, it was found that in Armco iron the energy lost by statical hysteresis varied approximately as the cube of the amplitude of the maximum stress.

CINDER AGGREGATES FOR CONCRETE BUILDING UNITS.

In coöperation with the National Building Units Corporation a study has been made of the physical characteristics of

cinders used as aggregate in the manufacture of cinder-concrete building units.

Fifty-seven different kinds of coal cinders, 44 of bituminous origin, 9 of anthracite origin, and 4 of both mixed, were obtained from 47 manufacturers throughout the country. These cinders were the products of high temperature combustion under forced draft. The samples received were from the regular run of such aggregate crushed to size.

Tests for weight, hardness, ignition loss, grading, and soundness have been made. Determinations of the weight per cubic foot of the dry rodded materials were made in accordance with the methods of A. S. T. M. Standard 029–27. The weights of the bituminous cinders ranged from 45 to 77 lbs./ft.^{3}, the average being 57. The average weight of the anthracite cinders was 57 lbs./ft.^{3}, individual samples ranging from 52 to 63 lbs. For the mixed cinders the average weight was 57 lbs./ft.^{3}, the maximum and minimum values being respectively 54 and 65 lbs.

The hardness tests were intended to give measures of the resistance of the cinders to impact and abrasion. The portions of the cinders that were too coarse to pass a No. 8 sieve were placed in a ball mill of definite size and shape and containing a definite number of flint balls of uniform size. The mill was rotated at a constant velocity for a fixed time. The percentage of the original sample then retained on the No. 8 sieve was taken as a measure of the hardness. With the bituminous cinders this measure of hardness ranged from 17 to 65 per cent., with an average of 36. The anthracite cinders gave values ranging from 2 to 14 per cent. with an average of 7, and the values for the mixed cinders ranged from 16 to 22 per cent. with an average of 20.

The ignition loss gave the total combustible content in the sample, including a slight amount of water absorbed by the material after being dried. For the bituminous cinders the average loss by weight was 27 per cent. with a maximum of 57 and a minimum of 7 per cent.; for the anthracite cinders the average was 35, the maximum 46, and the minimum 26 per cent.

Grading separations were made on the 3/4-inch, 3/8-inch, numbers 4, 8, 16, 30, 50, and 100 sieves. In only a few in-

stances were any particles retained on the 3/4-inch sieve and at the most only 3 per cent. of the total weight. Three-eighths inch usually was the maximum size. The amounts retained on the 1/4-inch sieve were as follows: Bituminous cinders, average 34, maximum 65, minimum 12 per cent.; anthracite cinders, average 19, maximum 30, minimum 6 per cent.; mixed cinders, average 27, maximum 34, minimum 17 per cent. The fineness moduli (the summation of the cumulative percentages retained, divided by 100) were:

Bituminous cinders, average 4.1, maximum 5.4, minimum 2.9; anthracite cinders, average 3.9, maximum 4.3, minimum 3.2; mixed cinders, average 4.0, maximum 4.4, minimum 3.4.

The soundness tests were made in accordance with a method devised by the Building Research Board in England. A 3-inch diameter pat, 1/2-inch high, was formed on a glass plate from a 1 : 3 mix by volume of a cementing mixture (equal parts by weight of Portland cement and plaster of Paris) and pulverized cinder. After three hours storage in moist air the pat was placed under water. Unsoundness was detected by cracking or curling of the edges of the pat within four days. All of the 57 cinders were classified as sound by this test.

MODULUS OF RUPTURE OF TYPICAL AMERICAN KAOLINS.

The Columbus branch of the bureau has been testing typical American kaolins from the largest producing areas. The following table is a résume of the modulus of rupture determinations on these clays at the various conditions.

Kaolin Designation.	Modulus of Rupture in lbs./in.².					
	Dry.	Cone 5.	Cone 8.	Cone 11.	Cone 14.	Cone 18.
North Carolina.....S	77	1,094	1,345	1,552	2,305	2,367
South Carolina.....T	33	148	283	646	439	516
Georgia.....U	72	95	292	348	587	640
Georgia.....V	16	139	131	533	621	785
Georgia.....W	32	309	268	692	474	1,100
Florida.....X	229	517	784	730	1,352	1,583
Florida.....Y	267	453	561	935	1,175	980

Note: The above cones are approximate, there being 1 to 2 cones variation depending on conditions.

The bars used in this investigation were made by extrusion from an auger brick machine, being cut by wire from the center of a standard $2\frac{1}{2}$ x $4\frac{1}{2}$ inch brick column. Thus it was hoped to eliminate surface skin effect. The clay was previously aged for 48 hours and pugged three times.

The results are not to be taken as precise values because of the apparent relative difficulties encountered in working kaolins for the production of pure clay bars. Warpage, kiln cracking, lamination, and dunting were encountered to some degree in all cases.

FIRE PROTECTION OF VALUABLE RECORDS.

The following is an abstract of a paper presented by S. H. Ingberg, chief of the fire resistance section of the Bureau of Standards, before the Fifth All-Ohio Safety Congress at Columbus, Ohio on April 21, 1932.

The vital importance of records is often not appreciated until loss, such as by fire, occurs. Other things of greater apparent intrinsic worth may receive more thought and care as regards methods of handling and safe disposition. Yet on the fact of preservation or loss of records in a destructive fire may depend the decision as to whether or not the establishment will be rebuilt and its business resumed. The high mortality of firms suffering disastrous fires can be traced in many instances to the loss of records forming the basis of tangible and intangible assets.

Other property and human values are also involved. Scattered throughout the length and breadth of the land, and indifferently protected, are the public records of birth, marriage, and death, deeds of conveyance and trust, testaments, court decrees, and the multitude of written evidence on which proof of citizenship, legal status, rights, and ownership depends. The loss of these records may mean expensive litigation and deprivation of rights and property that have required a lifetime of effort and sacrifice. Fire is an ever-present menace and is no respecter of persons or classes of property. Its toll for the country as a whole can be predicted within limits from year to year, and the only recourse by which the hazard for a given location or property can be

reduced below that of the average is by the application of prevention and protection measures of proven effectiveness.

From the standpoint of value, records have been classified as vital, important, useful, and non-essential. Vital records are those underlying the organization of an establishment and those giving direct evidence of legal status, ownership, accounts receivable and incurred obligations. Important records, while not irreplaceable, can be reproduced from original sources only at considerable expense. The loss of records classed as useful would cause temporary inconvenience, but otherwise entail no serious permanent disadvantage. Non-essential records are those that have no present value and should be destroyed. While some important records increase in value with age, most classes decrease in usefulness with time, which serves to place them successively in lower value classifications.

That records have money value is demonstrated by the very considerable expense that is being incurred for their protection. The value of some records can be definitely appraised in terms of the labor and material cost of their replacement. Other records have what has been termed consequential value which is stated in terms of the loss that would be sustained in their absence, records covering accounts receivable being an example.

The evaluation of the records of an establishment may lead to surprising results. As an example, an informal appraisal of the value of the property of the bureaus in the Department of Commerce gave the following results:

Value of buildings	$ 25,387,000
Inventory values of contents	10,875,000
Records and other uninventoried values	189,948,000

It is thus seen that uninventoried values, which pertain almost wholly to records, constituted over 80 per cent. of the total appraised value.

The length of time records should be retained is a matter that requires study for each establishment. Such study over a period of years should enable a consistent schedule of retention of useful records and destruction of those no longer useful to be established. Generally those in the higher value

classifications would be retained permanently or for longer period than the others. However, there are many exceptions to this rule. For some establishments legal limitations, such as statutes of limitations and the requirements of State or Federal regulatory bodies as for instance, the Interstate Commerce Commission, will govern the period of retention. A great many records are, however, eligible for destruction soon after they originate. As an example, one large organization found that approximately 30 per cent. of all its correspondence may be destroyed at once or within one month after the date of origin. Further suggestions on retention periods for different types of records are contained in schedules, such as those published by the National Fire Protection Association, the National Electric Light Association, and for some types of public utility companies, by the Interstate Commerce Commission.

The hazard of loss by fire can be decreased in varying degree by the application of measures designed to prevent the occurrence of fire, to protect records of value from destruction in case fire occurs, and by storing duplicates in a place where they would not be subject to loss by a fire that would affect the original record.

Very much can be done to decrease the fire hazard to record storage by observing well-recognized general principles of fire prevention and protection. This may attain a degree where further protection would not be required except possibly for the most vital records. If the records are housed in a fire resistive building with a minimum amount of interior and exterior combustible trim, with openings well protected against exposure fires, and with interior vertical and horizontal openings protected so that fire will not be communicated, a high degree of protection can be attained by the use of suitable equipment for housing the records. Such equipment should be of incombustible material with compartments as small as is consistent with the type of record and the office routine. Six-sided inclosure such as in filing cabinets and closed shelves is preferable. If these are placed on an incombustible floor finish and care is taken to avoid accumulations of unshelved or unfiled combustibles within the room, the possibility of a fire involving more than at the most a few

containers or compartments is quite remote. In non-fire resistive buildings such protection cannot be premised, since a general building collapse may occur from a fire anywhere within the building. General fire protection equipment, such as automatic sprinklers, effects a decided improvement under the latter conditions since fires are then checked in their initial stage. The possible water damage to records is generally overestimated considering that their main value depends upon legibility. General protection measures, such as those outlined above, are the only ones feasible where a large volume of records is involved. Specific buildings erected and equipped for the purpose are preferable, although good protection can be obtained in segregated portions of ordinary fire resistive buildings conforming with the structural and finish requirements above outlined.

Where structural or other conditions are unfavorable, and possibly under all conditions for very important records, further protection should be obtained by recourse to such means as record vaults and portable record containers. The walls and doors of vaults should have sufficient fire resistance and strength to withstand the fire exposures and impacts to which they may be subjected in the given location.

While the volume of records that can be profitably stored in insulated portable containers, such as safes, is limited and under some conditions the protection cannot be definitely predicted, this type of device is an important factor in record protection. The advantages consist in being able to place the container where the contents will be the most readily available. While the volume that can be thus protected profitably is limited, it will generally be found that a small percentage of the volume of records constitutes a very high percentage of the total value, and this portion, if protected, will afford a substantial assurance against serious loss.

One suggestion relative to the handling of charred or partly charred records may be pertinent. The filing cabinets or other containers should be left as far as possible in their original location and the contents of each drawer or compartment extinguished with a minimum amount of water. If this precaution is observed it may be possible to reconstruct a

partly charred file of records where it would be totally lost if taken out of its place or container. Charred records can frequently be read by eye due to the different color of the char under the writing.

The unnecessary retention of records that have served their useful purpose involves expense for equipment and storage space and also makes the really useful records less available. Frequently such records will be stored in locations and containers that will introduce a decided fire hazard to the building and its more valuable contents. A schedule for the retention of records should be supplemented with a coördinated program of destruction of those that have reached the limit of their useful period. This can best be accomplished by classifying records when they originate and providing means for destroying those that are deemed useless after a certain period. Where records of a given class originate in large volume, they may be placed in separate files and marked for permanent retention, retention over a period of years, or destruction within a comparatively short period. By this means the contents of the containers can be destroyed at given intervals without requiring sorting of the contents.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, MAY 18, 1932.

The stated monthly meeting of the Institute was called to order at three-forty-five P.M. by the President of the Institute, Mr. Nathan Hayward.

The Chairman stated that the minutes of the April meeting had been printed in full in the May number of the JOURNAL of the Institute and that, if there were no objections, the minutes would stand approved as printed. No objection was uttered and the minutes were declared approved.

The Chairman then stated that the next business of the meeting was the presentation of medals which had been recommended by the Committee on Science and the Arts and voted by the Board of Managers throughout the past year. Certificates of Honorary Membership were also presented.

The order of awards proceeded as follows:

PROGRAMME.

	Sponsors
Presentation of a Certificate of Honorary Membership to	
GEORGE A. HOADLEY, Sc.D. Swarthmore, Pennsylvania	Dr. H. McClenahan.
Presentation of Certificate of Merit to	
THOMAS RANDOLPH HARRISON, B.S. in E.E. The Brown Instrument Company Philadelphia, Pennsylvania	Mr. E. L. Clark.
Presentation of Longstreth Medal to	
JOSUA GABRIEL PAULIN System Paulin Aktiebolag Stockholm, Sweden Represented by Swedish Vice Consul	Dr. J. H. Hepburn.
Presentation of Wetherill Medals to	
HALVOR OLSEN HEM Toledo Scale Manufacturing Company Toledo, Ohio	Mr. W. P. Valentine.
MONROE CALCULATING MACHINE COMPANY, INC. Orange, New Jersey Represented by E. F. Britten, Jr.	Mr. J. C. Trautwine.
MESSRS. BALTZAR CARL VON PLATEN AND CARL GEORG MUNTERS Platen-Munters Refrigerating System Stockholm, Sweden Represented by Swedish Consul	Mr. J. L. Fitts.
FRANK WENNER, PH.D. Bureau of Standards Washington, D. C.	Dr. W. R. Wright.

Presentation of Levy Medal to
WAYNE BUCKLES NOTTINGHAM, PH.D. — Dr. T. K. Cleveland.
Assistant Professor of Physics
Massachusetts Institute of Technology
Cambridge, Massachusetts

Presentation of Clark Medal to
PHILIP THORNTON DASHIELL, PH.B. — Mr. T. F. Clark.
United Gas Improvement Company
Philadelphia, Pennsylvania

Presentation of Potts Medal to
GEORGE PAGET THOMSON, F.R.S. — Dr. F. Palmer.
Professor of Physics, Imperial College of Science and Technology
London, England
Represented by British Consul General

Presentation of Cresson Medals to
PERCY WILLIAMS BRIDGMAN, PH.D. — Dr. T. D. Cope.
Professor of Physics, Harvard University
Cambridge, Massachusetts

CHARLES LEGEYT FORTESCUE, LL.D. — Mr. W. C. Wagner.
Westinghouse Electric and Manufacturing Company
Pittsburgh, Pennsylvania

JOHN BOSWELL WHITEHEAD, PH.D. — Mr. C. W. Bates.
Dean, School of Engineering, Johns Hopkins University
Baltimore, Maryland

Presentation of the Franklin Medal and Certificate of Honorary Membership to
AMBROSE SWASEY, D.ENG., SC.D., LL.D. — Dr. James Barnes.
The Warner and Swasey Company
Cleveland, Ohio

Presentation of the Franklin Medal and Certificate of Honorary Membership to
GEHEIMRAT PROFESSOR PHILIPP LENARD, PH.D. — Dr. James Barnes.
Director, Radiological Institute, University of Heidelberg
Heidelberg, Germany
Received by the German Consul General in New York, DR. O. C. KIEP

After the presentation exercises, the following papers were read:

"Some Scientific Views," by Professor Dr. Philipp Lenard.

"Astronomers and Their Telescopes," by Dr. Ambrose Swasey.

The President then declared the meeting adjourned, at five P.M.

HOWARD MCCLENAHAN,
Secretary.

(An extended account of the proceedings of this Medal Day meeting will appear in an early issue of the JOURNAL.)

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, May, 11, 1932.)

HALL OF THE COMMITTEE,
PHILADELPHIA, MAY 11, 1932.

MR. EDWARD L. CLARK *in the Chair.*

The following report was presented for final action:

No. 2936: Railway Ballast Cleaner.

This report recommended the award of the John Price Wetherill Medal to the Industrial Brownhoist Corporation, of Bay City, Michigan, "In consideration of the high degree of ingenuity in design and execution of detail, embodied in a successful machine for cleaning railway ballast, resulting in a real contribution to railroading and the solution of a maintenance problem of great moment, especially under traffic conditions of extreme density."

The following report was presented for first reading:

No. 2948: Liquid Purification Process.

GEO. A. HOADLEY,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, May 25, 1932.)

RESIDENT.

MR. WILLIAM A. HEINE, Clock Maker, 31 South Fortieth Street, Philadelphia, Pa.

MR. IGOR V. MARKOFF, Industrial Research, The J. G. Brill Company, Philadelphia, Pa. For mailing: 4738 Baltimore Avenue, Philadelphia, Pa.

CHANGES OF ADDRESS.

MR. WILLIAM I. BALLENTINE, 1405 Indiana Avenue, LaPorte, Indiana.

MR. H. W. BUCK, 19 Rector Street, New York City.

MR. F. L. DUBOSQUE, 51 Bayview Avenue, Great Neck, N. Y.

MR. EDWIN D. A. FRANK, 1006 East State Street, Apt. 37, Milwaukee, Wisconsin.

PROFESSOR A. W. GOODSPEED, 4038 Walnut Street, Philadelphia, Pa.

MR. A. GRISWOLD HERRESHOFF, 472 St. Clair Avenue, Grosse Pointe Village, Michigan.

MR. SAMUEL EDWARD JOLLY, 533 Tenth Avenue, Prospect Park, Pa.

MR. HARRY H. KELLER, Cleuiston, Florida.

MR. DONALD L. KELLOGG, 10457 Ninety-first Avenue, Richmond Hill, New York

MR. A. ATWATER KENT, 4700 Wissahickon Avenue, Philadelphia, Pa.

MR. SIMON MILLER, NE. corner Seventh and Medary Streets, Philadelphia, Pa.

MR. ALEXANDER E. REOCH, care Radio-Keith-Orpheum Corporation, 1560–1564 Broadway, New York City, N. Y.

DR. WALTER F. RITTMAN, 5705 Solway Street, Squirrel Hill Station, Pittsburgh, Pa.

MR. CLIFFORD J. SUMMERS, 1051 Catalpa Avenue, Chicago, Illinois.
MR. CHRISTOPHER VAN DEVENTER, 76 East Monroe Street, Box 3, Chicago, Illinois.
MR. JOHN E. ZIMMERMAN, care Day and Zimmerman, 620 Packard Building, Philadelphia, Pa.

NECROLOGY.

Mr. William N. Allen, Germantown, Philadelphia, Pa.
Mr. John Ashhurst, Philadelphia, Pa.

LIBRARY NOTES.

RECENT ADDITIONS.

An unusual and valuable collection of works on mathematics and related subjects from the library of Dr. Marion Reilly, late Dean of Bryn Mawr College. Presented to the library by her mother, Mrs. John Reilly.

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BOOK REVIEWS.

COLLOID CHEMISTRY, THEORETICAL AND APPLIED. Collected and Edited by Jerome Alexander, Vol. III, first series on technological applications, 655 pages, illustrations, 15.5 × 23.5 cms. New York, The Chemical Catalog Co., Inc., 1931. Price $10.50.

The first two volumes of this set dealt with "Theory and Methods" and "Biology and Medicine" respectively. The one under review is the first half of "Technological Applications." Since "Nature pays no attention to the classifications we make for our own convenience" there are chapters in this volume which might have been in the first just as there is much of interest to the technologist in the earlier volumes.

An important factor in lubrication, painting, cleaning, and adhesion is wetting. Bartell (pp. 41–60) defines adhesional, spreading, and immersional wetting and gives a method for the determination of adhesional tension. After the surface has been wet, the strength of attraction between like and unlike molecules determines whether the wetting liquid will act as an adhesive or as a lubricant. McBain and Alexander make an effort (pp. 9–26) to clarify the subjects of cohesion and adhesion.

Although the patterns differ in character from those of crystals, X-rays give evidence of structure in colloids (pp. 27–40). "The formation of rubber-like and liquid-crystalline states of matter" are discussed by von Weimarn (pp. 89–102) "in connection with the classification of crystals according to their vectorial fields."

Although under certain conditions drops of liquid are spontaneously dispersed (pp. 61–4), usually it is necessary to provide mechanical aid. Colloid mills furnish very powerful shearing action but alone give rise to "turbid dispersions" (pp. 179–88). For some purposes these are preferable to materials which are truly peptized. Deflocculated graphite (pp. 547–54) is in this class although it requires much less severe mechanical treatment, as is often the case when deflocculators are added. While in many cases it is desirable to form colloidal particles, they often must be removed. Electrical precipitation (pp. 189–206) metafilters (pp. 215–24), and supercentrifuges (pp. 206–14) are means which may be employed. The flotation process (pp. 225–38) is used for the preferential separation of larger particles with differing surface reactions.

To one who is interested in silica and its derivatives this volume contains much of interest. The "crushing and fine grinding of quartz" may seem to be simple but a twenty page article (pp. 157–77) indicates that this is not necessarily true. The crystalline material may even be changed to an amorphous form. Lenher and his co-workers found this to be more pronounced when the grinding was done in water. Hydrated silica is usually produced by the acidification of soluble silicates (pp. 289–96). If properly prepared, silica gel is an excellent adsorbent for many vapors (pp. 119–34). A non-aqueous system of colloid chemistry may be found in glass (pp. 283–8) and still another in minerals (pp. 261–82) which leads to the colloidal effects found in geology (pp. 251–60). Ceramic bodies such as porcelain (pp. 297–350) and refractories (pp. 351–6) introduce new factors in addition to the silica and the relatively simple silicates while soils (pp. 559–90) are still more complicated. Here it may be necessary to resort to colloidal analysis (pp. 591–6) to simplify matters.

It is less evident that metallic systems offer another field for the study of colloids but we find there is a "colloidal state in metals and alloys" (pp. 413–38) and even "colloidal conditions in metal crystals" (pp. 439–48) and "colloidal systems in metallography" (pp. 449–58). Thin films on the surfaces of metals (pp. 473–6) decrease corrosion, which is intimately interwoven with colloid phenomena (pp. 477–90).

Another group of articles deals with carbonaceous materials. Graphite may be deflocculated in water or oil (pp. 547–54) and coal tar contains complex carbon-containing compounds (pp. 527–34). Petroleum (pp. 491–526) and asphalt (pp. 535–46) offer interesting colloid fields.

No brief review can even indicate all the information included in this book. Among other subjects included are contact catalysis, water supplies, chemical warfare, cements and mortars, and wheat and flour. Anybody who is interested in colloid or industrial chemistry should at least glance through the list of forty-two articles and, once that far, curiosity and interest may be counted upon to lead him further.

WM. STERICKER.

THE KINETICS OF HOMOGENEOUS GAS REACTIONS, by Louis S. Kassel, Ph.D., Associate Physical Chemist, U. S. Bureau of Mines Experiment Station, Pittsburgh, American Chemical Society Monograph Series, 330 pages, illustrations, 15 x 23.5 cms. New York, The Chemical Catalog Co., Inc., 1932. Price $6.50.

Enter another worthy member to the constantly growing ranks of American Chemical Society Monographs. With such an introduction it is not necessary to point out further that this book is written by a specialist in his particular field and it quite easily measures up to the standards of quality precedented by the preceding members of this notable series.

In the Preface, Dr. Kassel points out that "the progress of the subject of reaction Kinetics within the last decade has been rapid, but not always orderly." Probably the course of no homogeneous gas reaction has ever attained that supreme simplicity represented by those well-known chemical equations which merely represent the initial reactants and the final products. Only those who have worked on the determination of reaction rates can fully appreciate the complexities of the mechanisms involved in the course of a homogeneous reaction. The author, is apparently fully justified in basing his theoretical treatment entirely upon the methods of statistical mechanics rather than upon the less practical and more presumptuous thermodynamic functions. The subject matter has been divided into two parts, theoretical and experimental and the attempt is made to have each part complete in itself. Such an arrangement greatly enhances the utilitarian value of the book for readers of varying needs. Thus, the mathematical physicist's main interest would lie in the theoretical section while the second or experimental portion would have direct appeal to an experimental chemist concerned solely with the measurement of reaction rates.

In the introduction the author engagingly draws a distinction between Thermodynamics and Kinetics through the choice of apt similes. He is frank to say he is interested in reaction rates for their own sakes and that the primary purpose in writing this book was to provide a summary of the present situation

in the field of reaction rates for the author's personal use. No doubt, readers will be fully appreciative of the opportunity to secure this summary in the form of an A. C. S. Monograph.

Part I—Theory, begins with an introductory chapter on elementary reactions and their energy of activation. After a short treatise on distributing laws, bimolecular, trimolecular and unimolecular reactions are discussed in the order named. As might be expected of Part II—Experimental, many examples of first, second and third order reactions are given and discussed in the light of statistical mechanical theory. Two additional chapters have been alloted to the discussion of some of the better known complex reactions. Appendix I consists of a brief summary of the radiation hypothesis while number II lists the heats of dissociation for some of the more common molecules.

T. K. CLEVELAND.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS:

Report No. 408. General Formulas and Charts for the Calculation of Airplane Performance, by W. Bailey Oswald, 50 pages, illustrations, quarto. Washington, Government Printing Office, 1932. Price twenty-five cents.

In the present report submitted to the National Advisory Committee for Aeronautics for publication the general formulas for the determination of all major airplane performance characteristics are developed. A rigorous analysis is used, making no assumption regarding the attitude of the airplane at which maximum rate of climb occurs, but finding the attitude at which the excess thrust horse-power is maximum.

A comprehensive study of full-scale data for use in the formulas is made. Using the results of this investigation, a series of performance charts is drawn for airplanes equipped with modern unsupercharged engines and fixed-pitch metal propellers.

Equations and charts are developed which show the variation of performance due to a change in any of the customary design parameters.

Performance determination by use of the formulas and charts is rapid and explicit. The results obtained by this performance method have been found to give agreement with flight test that is, in general, equal or superior to results obtained by present commonly used methods.

Report No. 411. Theory of Wing Sections of Arbitrary Shape, by Theodore Theodorsen, 13 pages, illustrations, quarto. Washington, Government Printing Office, 1931. Price ten cents.

This paper presents a solution of the problem of the theoretical flow of a frictionless incompressible fluid past airfoils of arbitrary forms. The velocity of the two-dimensional flow is explicitly expressed for any point at the surface, and for any orientation, by an exact expression containing a number of parameters which are functions of the form only and which may be evaluated by convenient graphical methods. The method is particularly simple and convenient for bodies of streamline forms. The results have been applied to typical airfoils and compared with experimental data.

Report No. 412. The 7 by 10 Foot Wind Tunnel of the National Advisory Committee for Aeronautics, by Thomas A. Harris, 9 pages, illustrations, 23 × 29 cms.. Washington, Government Printing Office, 1931. Price ten cents.

This report presents a description of the 7 by 10 foot wind tunnel and associated apparatus of the National Advisory Committee for Aeronautics. Included also are calibration test results and characteristic test data of both static force tests and autorotation tests made in the tunnel.

The tunnel air flow is satisfactory. The velocity, at the model location, is uniform within ± 0.2 per cent. and the air flow direction is parallel to the axis of the jet within ± 0.3°.

The tunnel is equipped with a 6-component indicating balance, on which the three forces and three moments may be measured directly and independently. All tests are made at the same dynamic pressure on models having the same area and aspect ratio. By this arrangement, the results are obtained in coefficient form and very little time is required to reduce the test data.

The balance may also be used for making stable autorotation tests or for measuring the rolling moment due to roll. In such cases the force-test model support is replaced by one designed for rotation tests.

Report No. 413. A Method for Computing Leading-Edge Loads, by Richard V. Rhode and Henry A. Pearson, 12 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1931. Price ten cents.

In this report a formula is developed that enables the determination of the proper design load for the portion of the wing forward of the front spar. The formula is inherently rational in concept, as it takes into account the most important variables that affect the leading-edge load, although theoretical rigor has been sacrificed for simplicity and ease of application. Some empirical corrections, based on pressure distribution measurements on the "PW-9" and "M-3" airplanes, have been introduced to provide properly for biplanes.

Results from the formula check experimental values in a variety of cases with good accuracy in the critical loading conditions. The use of the method for design purposes is therefore felt to be justified and is recommended.

Report No. 414, The Effect on Airplane Performance of the Factors that must be Considered in Applying Low-Drag Cowling to Radial Engines, by William H. McAvoy, Oscar W. Schey, and Alfred W. Young, 19 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1932. Price twenty cents.

This report presents the results of flight tests with three different airplanes using several types of low-drag cowling for radial air-cooled engines. The greater part of the tests were made with a Curtiss XF7C-1 ("Sea Hawk") with a 410 hp Wasp engine, using three fuselage nose shapes and six types of outer cowling. The six cowlings were: A narrow ring, a wide ring, a wide cowling similar to the original N.A.C.A. cowling, a thick ring incorporating an exhaust collector, a single-surface cowling shaped like the outer surface of the exhaust-collector cowling, and a polygon-ring cowling, of which the angle of the straight sections with the thrust line could be varied over a wide range.

The addition of outer cowlings to the XF7C-1 resulted in speed increases of from 6 to 20 miles per hour, depending upon the type of cowling and the fuselage shape. The narrow-ring cowling gave the least increase in speed and the single-surface cowling the greatest. A reasonably wide cowling with its leading edge behind the front plane of the engine cylinders gave the best performance of the plain-ring types of cowling. The optimum range for the angle of the cowling section with the thrust line was only 3° or 4°; the position of the range was dependent upon the shape of the fuselage and the shape and location of the cowling section. In general the engine temperatures increased as the high speed was increased, both of these effects being directly contributed to by reductions in the amount of air flowing past the cylinders. The use of cowlings had very little effect upon the performance in climb.

Report No. 418. Preliminary Investigation of Modifications to Conventional Airplanes to Give Nonstalling and Short-Landing Characteristics, by Fred E. Weick, 16 pages, illustrations, quarto. Washington, Government Printing Office. Price five cents.

This report describes flight and landing tests made on a group of conventional airplanes at the laboratory of the National Advisory Committee for Aeronautics. The upward deflection of the elevators was limited to the point where the airplanes could not be made to spin without the aid of power. With the elevator travel thus limited, the airplane in every case had good lateral stability and good aileron effectiveness up to the highest angles of attack which could be obtained in a glide, although this was not true in any case without the limited control. All ordinary flight maneuvers could be performed with the elevator displacement limited, but usually there was not sufficient control to get the tail down for a normal 3-point landing.

In order to investigate the feasibility of making landings by gliding straight to the ground with the full but limited amount of tail-depressing longitudinal control in use, glides were made and the vertical velocities measured. These were found to range from 12 to 24 feet per second for the various airplanes tested; and since the lateral stability and control in the glides with the control sticks full back to the limited positions were satisfactory, it seemed that landings could be satisfactorily made in this manner if reasonably long-stroke shock-absorbing landing gears were provided.

As this type of landing seemed to have several advantages, one of the airplanes (the Verville "AT") was fitted with long-travel shock-absorber struts and actual landing tests were made in which the distances, as well as the accelerations upon contact with the ground, were measured.

LA PHOTOGRAPHIE, par Maxime Hesse et Claude Amédée-Mannheim, Anciens Élèves de l'École Polytechnique, 204 pages, illustrations, 11 x 17 cms. Paris, Librairie Armand Colin, 1932. Price, in paper, 10 f. 50.

The modern photographer need know little concerning the physico-chemical principles which govern the behavior of light-sensitive films, or the geometry of photographic optics. Manipulative skill, composition, lighting, and the all-important detail of time of exposure are his chief preoccupation to derive superior results from the uniformly reliable photographic products which are readily procurable. If, perchance, he is equipped with the prerequisite training, there is

ample literature to pursue to the fullest extent the scientific aspects of the art. On the other extreme, there is also ample supply of books containing the thousand-and-one items of practical value on the empirical side of the subject. It is between these extremes that the authors have found a field not satisfactorily covered.

The book covers in a summarized form all those topics which are included in the principles of the modern practice of monochrome photography, namely—the lens, the camera, the negative, and the positive. The treatment of the aberrations of lenses is necessarily sketchy, but the important features are pointed out and described. In the section on the negative, the principles of sensitometry, the work of Hurter and Driffield, is discussed at considerable length. Little mathematics is used, but the small amount employed is simple and clarifying.

The book should prove of value to one who desires a well-balanced descriptive summary of the methods of monochrome photography.

LUCIEN E. PICOLET.

LE CALCUL DES DIFFERENCES FINIES ET SES APPLICATIONS. Par Alfred Henry, Membre de l'Institut des Actuaires de Londres. Traduit de l'Anglais par A. Sallin. 212 pages, 16 x 25 cms., paper. Paris, Librairie Scientifique Hermann et Cie., 1932. Price 50 francs.

Every treatise on algebra, that is the usual higher algebra of a college course, contains a more or less extended account of the method of differences for the summation of certain series. Those texts which deal with the computation of logarithmic tables or other tables, also give the method of finite differences a considerable amount of attention in connection with the process of interpolation. Thus a reader who is entering upon a serious study of the calculus of finite differences has available easily accessible sources of information for a preliminary notion of the subject.

In the present volume, the author provides the means for an adequate and not needlessly exhaustive study of the subject. Of the twenty chapters, eight are devoted strictly to the derivation of general formulas of finite differences and their application to interpolation in its various aspects, its most important application; to the summation of series; and to functions of two variables. The tenth to the nineteenth chapters cover the subject-matter of the usual texts on the differential and integral calculus in which is included a chapter on the relation between the differential calculus and the calculus of finite differences. The final chapters are respectively on approximate integration, including a discussion of Simpson's rule and the like, and an applicable account of the theory of probability. An adequate number of worked examples are provided throughout the work as well as practice examples with answers.

The treatment is formal and sound and the reader who desires a deductive and applicable exposition of the calculus of finite differences and its relation to the infinitesimal calculus will not err in choosing this book.

L. E. P.

PUBLICATIONS RECEIVED.

The Last Cruise of the Carnegie, by J. Harland Paul, 331 pages, illustrations, 15 x 23 cms. Baltimore, The Williams & Wilkins Company, 1932. Price $5.00.

Meet the Sciences, by William Marias Malisoff, 196 pages, 13.5 x 21.5. Baltimore, The Williams & Wilkins Company, 1932. Price $2.50.

Thermionic Vacuum Tubes, and Their Applications, by E. V. Appleton, 117 pages, illustrations, 10.5 x 17 cms. New York, E. P. Dutton & Co., Inc. Price $1.25.

National Advisory Committee for Aeronautics, Bibliography of Aeronautics, 1930, by Paul Brockett, 261 pages, 18 x 26 cms. Washington, Government Printing Office, 1932. Price, in paper, fifty cents. Technical Notes, No. 415, Preliminary Investigation of Rolling Moments Obtained with Spoilers on Both Slotted and Plain Wings, by Fred E. Weick and Carl J. Wenzinger, Langley Memorial Aeronautical Laboratory, 11 pages, diagrams, 20 x 26 cms. Washington, Committee, 1932. No. 416, Characteristics of Two Sharp-Nosed Airfoils having Reduced Spinning Tendencies, by Eastman N. Jacobs, Langley Memorial Aeronautical Laboratory, 5 pages, diagrams, 20 x 26 cms. Washington, Committee, 1932.

U. S. Department of Commerce, Wood Utilization, Treated Lumber Its Uses and Economies, Report of the Subcommittee on Retail Distribution of Treated Lumber of the National Committee on Wood Utilization, 42 pages, tables, illustrations, 15 x 23 cms. Washington, Government Printing Office, 1930. Price fifteen cents.

CURRENT TOPICS.

X-Rays as a Research Tool in Chemistry and Industry.—(*Ind. and Eng. Chem.*, Feb. 1932.) As a contribution to a symposium on new research tools GEORGE L. CLARK has given us a critical survey of that part dealing with the numerous and varied applications of X-rays. In the industrial field the use of X-rays for examining the gross structure of metals is probably the best known and most extensive mode of application. X-ray examination promotes safety by detecting defective castings and forgings. Steel Dewar flasks for holding gases under high pressure are put through an X-ray examination as a matter of routine. In Germany, special cars have been constructed whereby they can X-ray a locomotive already built and in service and determine soundness of the boiler walls and fire-box plates. For very thick forgings or castings, a very penetrative form of X-ray is required. This has led to the ingenious use of the very "hard" X-rays from radium. The taking of a radiograph is necessarily slow but the method has been successfully used in examining stern posts of navy cruisers after they are in place.

Ever since their discovery, X-rays have played an outstanding part in the determination of atomic structure. One of the more recent developments has been the use of data from the scattering of X-rays by gases to determine electron distribution in atoms. Every chemical element possesses the ability to emit or absorb X-rays of definite wave-lengths. Because of this characteristic, X-rays have found many important applications in both qualitative and quantitative chemical analysis. Several advantages may be attributed to this method of analysis. By it, extremely small amounts of material may be detected, recent discoveries of the remaining elements are examples. Mixtures of rare earths or metals of the platinum group render separation by chemical manipulation very tedious. Their component parts may be readily determined by an X-ray examination. An X-ray analysis may be performed upon unprepared materials making the removal of impurities, separation from other substances, or loss in material unnecessary. This method should be especially applicable to gems and rare metals. Moreover, the process of X-raying is relatively safe, rapid, and permits the registration of results upon a photographic plate thus eliminating to a large degree the personal factor. Some idea of the value of X-rays for detecting impurities may be had from the fact that often 1 part in 10,000 can readily be detected.

Some investigators have detected 1 part of iron in 300,000 parts of zinc.

Other applications of X-rays have been (1) the identification of the crystal systems of iron alloys and the modes of linkage of the silicon atoms in many natural silicate rocks, (2) grain-size measurement in both the colloidal and microscopic ranges, (3) detection and estimation of internal strain in crystals and (4) practical studies of rolling and heat-treating metals. The author reports interesting results from the X-ray study of molecular orientation in surface films as performed in his laboratory. Last of all we must not fail to recognize the great help X-rays have been to the organic chemist. They have added greatly to the knowledge of the molecular structure of ring compounds (benzene, naphthalene, etc.), cellulose in the form of wood, cotton, and rayon; wool, silk and rubber.

T. K. C.

The Arlington Memorial Bridge.—(*Engineering News-Record*, Mar. 3, 1932.) According to R. S. FOULDS the movable span of the Arlington Memorial Bridge is one of the largest and heaviest bascules in the world. The bridge consists of eight concrete barrel arches of 166- to 180-ft. spans and the 216-ft. bascule in the center which is faced with ornamental metal work to harmonize with the white granite facing of the arches.

Each bascule leaf consists of two trusses, one on each side. These trusses rest upon a trunnion which in turn rests upon two bearings placed just outside of each truss. The trunnion forms the axis about which the leaf turns. The rear ends of the trusses extend back beyond the trunnion and from these ends is hung the counterweight also upon a trunnion. This arrangement permits the weight to move parallel to itself whenever the leaves revolve about the main trunnions.

Each leaf is operated by two motors direct connected to a speed reducer which, through an equalizing device transmits equal quantities of driving power to two pinions engaging rack segments mounted upon the bascule trusses. Four solenoid brakes are provided for each leaf which are capable of holding the leaf open against a wind pressure of 15 lb. per sq. ft.

The counterweights were constructed in the position assumed when the leaf is closed. To do this a steel falsework had to be erected upon the floor of the pit into which the weight drops when the leaf is raised. The volume of each counterweight is 689 cu. yd. and the required weight per cu. ft. to average 260 lb. In order to impart such a mass to the concrete, the inclusion of 3,000 gross tons of steel scrap would have been necessary. Too much time

would have been consumed in accumulating this quantity and so, after considering various materials, an entire shipload of Swedish ore was purchased. This ore has a specific gravity of 4.94 and was carefully proportioned with concrete and steel scrap to give the required weight per cu. ft. It is rather startling to realize that 146 tons of water are retained by the mixture forming the counter-weight. T. K. C.

An Innovation in Rail Cars.—*The Engineering News-Record* for Mar. 3, 1932, describes the many radical departures from accepted practices to be found in the new rail car recently built at the plant of the Edward G. Budd Manufacturing Co.

The new car is designed to carry 40 passengers and 1,500 lb. baggage. Its total weight is 13,548 lb. or an allowance of 340 lb. per passenger as compared with 1,000 lb. in a standard railway coach and 5,000 lb. for Pullman sleepers. Motive power is about 90 hp. as against 300 to 900 hp. used to propel the older-style rail cars.

The framework of the car is notable in that it is constructed almost entirely of specially formed structural shapes of stainless steel ranging in thickness of 0.01 to 0.04 in. and having a tensile strength of 150,000 lb. With metal this thin riveting will not be satisfactory and ordinary welding methods tended to alter the chemical composition of the metal in the weld and corrosion would occur. These difficulties were overcome by the working out of a new method known as "shot-welding," in which the metal is electrically spot-welded so quickly there is not time for composition changes to take place.

In order to economize further in weight the windows are fixed. Ventilation is accomplished by a small air-conditioning plant providing heated air in winter and cooled in summer. Walls and floors are both well insulated. Each of the two trucks carries six flanged steel wheels fitted with patented demountable pneumatic tires carrying 85 lb. pressure. The air chamber is dumbbell in shape. The car may be operated safely with one or all tires deflated. A tire life of 20,000 miles is expected. The brakes are of the automobile type and the car operating at 60 miles per hour may be brought to a full stop in 400 ft. Operating costs are estimated at from 15c. to 25c. per mile. T. K. C.

Deep Gorge.—The Department of the Interior informs us that the well-advertised Royal Gorge of the Arkansas River near Canon City now has a worthy rival in the east, only recently recognized as such. The stream in the Royal Gorge is so small it taxes a

person's credulity to believe that such a puny force could have cut for itself a chasm 1,100 feet in depth. Now in West Virginia it has been discovered that the canyon of New River has in some places a depth of 1,200 feet and at the bottom is scarcely wider than the stream that has carved it. This canyon is to be found in that section of the state known as the Beckley quadrangle, located in the heart of the New River coal field, famous for its "smokeless" coal.

T. K. C.

The Faculty of Sciences.—From England comes the announcement of the formation of a Faculty of Sciences. This organization lists as its pricipal object that of providing an international organization representing the general interests of Science as a whole and to promote every possible facility for intercourse between the various specialized branches. The *Chemical News and Journal of Industrial Science* has been adopted as the official organ.

T. K. C.

Made-To-Order Earthquakes.—When the operators of a limestone quarry in Manistique, Mich., set about to prepare an enormous blast Science Service arranged that this explosion should be of service to science in addition to that of dislodging 1,250,000 tons of limestone. 430,000 pounds of dynamite and similar explosives, planted in 5,000 separate holes, were set off at one time. The time of detonation was prearranged and determined by means of a chronometer set by radio standard time signals from Washington. All this done in order that seismographic recordings of the shock might readily be identified. It is hoped that additional information regarding the earth's crust may be gained through a study of the seismograph records of the shocks passing through it.

T. K. C.

Concrete Mulch.—According to Clip Sheet No. 714 of the U. S. Department of Agriculture, back-yard gardens ultimately may be paved instead of plowed. The department is experimenting with permanent mulches of concrete, iron, cinders, zinc, aluminum, and other substances which cover the surface of the ground, except for a small space where the plants grow. In the tests beans, peas, strawberries and various other small fruits have grown as well under the permanent mulch as with ordinary cultivation.

A mulch may consist of blocks a few inches thick and 9 and 12 inches wide covering the ground with rows 1½ inches wide between them. Advantages of the permanent mulch are stated to be the conservation of moisture and the control of weeds. In addition it

warms the soil earlier in the season and keeps it warm longer in the fall. The blocks should be covered with asphalt or painted black in order that they may absorb more heat. T. K. C.

Sending 8,000 Miles for Pork.—No one can accuse the U. S. Department of Agriculture of lack of thoroughness in studying the suitability of American pork for British consumption. Hogs raised in Montana were cured in Milwaukee then sent to the English market. Later, an English broker selected four of these so-called American Wiltshire sides and, along with four each from Ireland, Denmark, Poland and Sweden, shipped them to America.

The sides were taken to the U. S. Animal Husbandry Experiment Farm at Beltsville, Md., where they were examined for soundness, photographed, measured, cut and chemically analyzed. Last of all the meat was cooked and tested by experts for palatability.

Among other things the study indicated that there are satisfactory hog types in America that can produce acceptable Wiltshire sides for the British market and that heavy curing probably is not essential to insure the product reaching the foreign market without deterioration. T. K. C.

Corrosion Protection in Cracking Equipment.—According to J. C. MARRELL and GUSTAV EGLOFF in a paper read before the New Orleans meeting of the American Chemical Society, the A. O. Smith Co. of Milwaukee have developed a method of installing alloy liners in high pressure cracking vessels. The alloy sheet linings are applied to the steel plate before the plates are formed or rolled to the finished shape. The two metals are held together under several tons pressure during the welding process. A resistance type of weld is used, an electric current being used to heat the metals to the point of fusion. These points of fusion of the steel and alloy are sufficiently close to almost overlap. The bond between the liner and the wall of the vessel will develop a shearing strength of 8,000 to 15,000 pounds. In the field, these alloy linings can be installed by first spot welding the plates to the walls of the vessel then butt welding the plates. T. K. C.

Permanency of Creosoted Piles.—(*Engineering News-Record*, Mar. 10, 1932.) At the annual convention of the American Wood Preservers Association, FRANK R. JUDD reports on the examination of creosoted piles driven in 1911. Twenty years later their appearance was that of having just been driven. Borings indicated the heart and the outer treated portion to be perfectly sound. The creosote had penetrated to a depth of 2 1/2 inches, the odor was

still strong and the borings contained sufficient oil to soak and discolor their paper container. These piles had been driven in a sandy clay alternately wet and dry.

T. K. C.

Cotton Sheets for a Roadbed.—(*Engineering News-Service*, Mar. 10, 1932.) S. C. MCCARTY, division engineer in the Texas state highway department, describes the use of cotton cloth for stabilizing a light bituminous surfacing. As a base for this road crushed-flint, clay gravel was put on to a depth of 10 in., and, after shaping and rolling, was opened to traffic for 30 days. At the end of this period a prime coat of light tar was applied at the rate of 0.3 gal. per square yard. Seventeen hours after this application, a cotton fabric was spread longitudinally along the entire surface. The fabric was 38 in. wide and weighed 3 oz. per yard. The laying of the cloth was followed by the application of about 0.5 gal. per square yard of 250-penetration asphalt at 240° F. This was immediately followed by 1/4 to 3/4 in. crushed limestone, after which the surface was rolled. It is yet too early to say whether decrease in maintenance costs will justify continued use of cotton fabric.

T. K. C.

High-Power Turbine Installation.—(*Power*, Mar. 15, 1932.) Between Columbia, Pa., and tide water the Susquehanna river falls 225 feet. Practically all this head is utilized by three power plants the ultimate capacity of which should reach 1,250,000 horse power. The third plant has recently been placed in operation at Safe Harbor, Pa. This plant is designed to operate under a head of 55 ft. and attain an ultimate horse power development of 510,000. The power house and dam comprise a structure 4,865 ft. in length. The most notable feature concerning this plant is the type of turbine installed. There are to be six 42,500-hp. automatically adjusted—blade propeller—power units. With this type of machine the angle of the propeller blades is altered by means of a governor to meet changes in the load and thus maintain a high degree of efficiency. In addition, the relation between blade angle and gate opening can be varied manually to compensate for changes in the head. In such installations the governor must perform a double duty of regulating speed and adjusting the pitch of the propeller blades.

T. K. C.

Smoke Under the Microscope.—(*Power*, Mar. 15, 1932.) At a recent meeting of the American Institute of Electrical Engineers Dr. E. E. Free demonstrated sampling and testing apparatus used in

the study of atmospheric smoke pollution. Several methods for securing samples of smoke particles are known but none of them are considered to be 100 per cent. satisfactory. A method, much favored in the past was to allow a jet of air to impinge upon a greased plate to which the smoke particles would adhere. However, the grease was found to be "selective" that is, it would retain particles of a certain kind and allow the others to escape. Two sampling methods enjoying scientific sanction are that of drawing the air through a filter upon which the smoke particles are caught and that of allowing a jet of air from a small orifice to impinge upon a microscope slide, producing thereon a spot of smoke deposit which may then conveniently be examined microscopically.

These microscopic studies have demonstrated that various power plants produce distinctive types of smoke specimens. In some samples, globular spheres of ash are predominant; in other, small slivers of carbon. The particles may be counted by aid of a ruled plate.

Dr. Free estimates that on the clearest days one cubic foot of city air will contain about 50,000 particles. On a very smoky day this number may increase to 3,000,000. Rain and snow are relatively ineffective for removing these smoke particles from the atmosphere while on the other hand a good strong wind brings about a rapid dispersion.

There exists much discussion as to whether the greater proportion of the smoke arises from industrial plants or domestic sources. Dr. Free contends that in New York city domestic smoke comprises 90 per cent. of the total and that less than 5 per cent. comes from utility plants. Also, in this particular district, the smoke consists of one-third ash particles rather than twice this quantity as is often supposed. T. K. C.

Improving Pines.—One wonders how the quality of growing pines can possibly be improved by the presence of a substantial mixture of second-growth hardwoods of the same age. Recent studies of the United States Forest Service (U. S. Dept. of Agric. Clip Sheet No. 717) show that the shorter broad-leaved trees help materially in shading out and causing natural pruning off of the lower branches of the pines, promoting earlier formation of clear lumber in the growing pine trunks. Best results are found where the stand consists of about 20 per cent. of well-distributed hardwoods.

T. K. C.

Strength of Wood.—(U. S. Dept. of Agric. Clip Sheet No. 718.) Another good reason for seasoning wood emanates from a report of

the Forest Service which states that dry wood is as much as two and one-half times as strong as the same wood in the green, or natural growing state.

To the Steer's Taste.—(U. S. Dept. of Agric. Clip Sheet No. 719.) At the Animal Husbandry Farm, Beltsville, Md., a field was sown with twenty-five different grasses and legumes. A group of steers was allowed in the field after growth had taken place and their preferences for certain plants were observed. The legumes such as clovers, alfalfa and lespedeza led in this unique palatability test.

T. K. C.

A New and Improved Lemon.—(U. S. Dept. of Agric. Clip Sheet No. 719.) An example of fortuitous inheritance of Mendelian characteristics is to be found in the development of a new variety of citrus fruit produced by crossing the common Mexican lime with the ordinary lemon. This hybrid fruit resembles a lemon in size and flavor and is resistant to withertip a disease of limes and to scab a serious disease of lemons in Florida.

A Phosphorous Diet for Wild Ducks.—Needless to say such a diet was fatal. Learning on March 18 that ducks were dying in great numbers in the tide water area of a tributary to the Potomac River, the Biological Survey of the U. S. Department of Agriculture undertook to investigate. Autopsies disclosed the presence of phosphorus in the birds' digestive organs, in which small, pale amber particles of the substance were readily detectable. The source of this poisonous chemical was found to be the phosphorus-containing rifle grenades fired over the waters of the creek during target practise. Some peculiar characteristics of this deadly element enables it to retain its damaging effectiveness for periods as great as several years. Phosphorus will remain unchanged when immersed in water, and there in the marshes at the bottom of shallow pools it retains its unimpaired powers of destruction ready to exert themselves at the first opportunity.

T. K. C.

Bagasse, Sugar Cane Refuse, New Source of Rayon.—To the U. S. Department of Agriculture must be given credit for this recent development of a method of treatment which establishes bagasse as satisfactory source of cellulose used in rayon manufacture. D. F. J. LYNCH and M. J. GASS have found that by using low-priced nitric acid, a high grade cellulose, base material for rayon, can be obtained from bagasse, the waste from sugar cane after the

sugar has been extracted. The method, known as the nitric acid pulping process, consists of soaking the raw material in a weak nitric acid solution for several hours at a medium temperature, then heating it for an hour and finally washing and boiling in dilute sodium hydroxide to produce a soft, bleachable pulp.

The feasibility of this process rests mainly upon economic considerations. From 250,000 to 500,000 tons of bagasse accumulate each year at the sugar cane mills of the United States. Much of it is being used for manufacturing an insulating building material. Since most of the cane mills are in regions of fuel scarcity they are dependent upon bagasse for heat and power. Probably the price the pulp manufacturer would have to pay depends somewhat on the cost of replacing bagasse with coal, oil or gas as fuel. The greatest impetus toward commercial development can be attributed to the cheaper supplies of nitric acid.

The process has certain advantages over the older methods of processing bagasse. Open instead of pressure tanks are used with lessened consumption in heat, power and time. The nitric solution may be used over for several times. The department regards the process as now developed to the point where commercial interests can work out the practical problems of manufacture.

T. K. C.

Wild Flax.—The U. S. Dept. of Agriculture reports (Clip Sheet No. 721) having discovered a wild, yellow-flowered flax, so adapted by nature to a dry climate that it drops its seeds only when rain falls. Such flax behaves exactly opposite to the domestic varieties.

To operate in this remarkable way, the plant must possess a number of specialized parts. The flax boll, which contains the seeds, is partly covered with a waxy, waterproof coating but has tiny openings near the bottom of the boll. Beneath the waxy outer coating is a porous layer which soaks up water rapidly as it enters the openings. As the water is absorbed, the porous layer swells and pushes open the fine segments of the boll, allowing the seeds to drop. The boll will open in a few moments if wet by rain or dew, and closes again when it dries.

T. K. C.

Honey in Tubes.—(U. S. Dept. of Agric., Clip Sheet No. 721.) Honey may now be obtained in collapsible tubes and may be dispensed very much after the manner of tooth paste and shaving cream. Aside from squeezing tubes in order to whiten the teeth and soften the beard, one may now do it to sweeten the bread.

T. K. C.

The Deaf Shall Hear.—(*Science News-Service.*) Many of us have listened (?) to a phonograph record by holding one end of a broom-straw in our teeth and allowing the other end to drag in the groove of the revolving record. Thus, we heard the sounds by virtue of their transmission through the teeth and bones of the head to the inner ear.

Dr. Frederick Bedell, physicist of Cornell University, has recently completed a device which enables the deaf and hard of hearing to receive sounds not by way of the outer and middle ear passages but through their teeth or the bones of their head. This so-called "deaf speaker" does not broadcast sound, but carries it directly to the person who holds the receiving part of the apparatus between his teeth or pressed against cheek bone or forehead. To other persons in the room, the apparatus is silent.

Construction of the "speaker" is founded on the theory that the majority of persons with defective hearing have a defective middle ear. Part of the middle ear's duty is to modify the incoming sound waves before transmitting them to the inner ear. Because of this the "deaf speaker" does not transmit to the head bones the sound waves in their original form but first makes the necessary alterations in frequency and amplitude.

T. K. C.

Iodine Monobromide. JACOB CORNOG AND R. A. KARGES (*Jour. Am. Chem. Soc.*, 1932, *54*, 1882–1887) have devised a new method for the preparation of iodine monobromide. Liquid chlorine is introduced into a tared flask which is cooled with solid carbon dioxide and ether. A mass of solid iodine approximately one-half the molar equivalent of the mass of chlorine is added; the contents of the flask become solid. The flask and its contents are permitted to warm gradually to room temperature. Uncombined chlorine evaporates during this process. The flask and its contents are weighed. Knowing the weight of the iodine previously added, it is now possible to calculate and add a mass of iodine just sufficient to convert the crude product into the monochloride, which is then purified by recrystallization. Iodine monochloride is a polar or associated liquid which freezes at 27.19° C.

J. S. H.

Reactions of Incandescent Tantalum. MARY R. ANDREWS (*Jour. Am. Chem. Soc.*, 1932, *54*, 1845–1854) has studied the behavior of filaments of tantalum when heated in low pressures of certain gases. Nitrogen is absorbed, and a nitride TaN may be formed. The absorption of hydrogen is governed by the concen-

tration of atomic hydrogen in the gas. Absorption of oxygen gives rise to the formation of an oxide. In the vapors of hydrocarbons, such as benzene or naphthalene, a dark gray carbide Ta_6C_5 or a yellowish brown carbide TaC forms.

J. S. H.

Why Blunt Nails? (U. S. Dept. of Agric. Clip Sheet No. 723.) The Forest Products Laboratory has found that blunt-pointed nails cause less splitting in nailing handles than do sharp-pointed ones. A manufacturer of implement handles has adopted blunt nails in an attempt to reduce the large amount of splitting accompanying the nailing operation. As a result, the splitting of handles was reduced to less than one-half of one per cent. It would be interesting to have worked out the difference in the stresses in the wood produced by sharp and blunt nails respectively.

T. K. C.

Is White or Red Lightning the More Dangerous? (U. S. Dept. of Agric. Clip Sheet No. 723.) It is interesting to learn that red lightning, although in no way different from the white variety, is seldom reported by Forest Service lookouts as the cause of forest fires. It is still more interesting to hear DR. W. J. HUMPHREY'S explanation for the difference in the culpability of these high-tension atmospheric electric discharges.

Doctor Humphrey points out that in rainless air, electric discharges owe their light entirely to the two gases, oxygen and nitrogen, and therefore are white or bluish white. However, an electric discharge through heavy rain may dissociate some of the water vapor along its path and thus produce, in addition to the light of oxygen and nitrogen, that also of hydrogen, which is brilliantly red.

Red lightning, coming through rain, strikes only wet objects, which, of course, greatly reduces its fire hazard. White lightning, on the other hand, may strike dry fuel, which is easily fired.

T. K. C.

Recent Improvements in Monel Metal Forgings. The International Nickel Co. reports that as a result of recent developments in the forging of Monel Metal rods, shafts, spindles, etc., in large diameters, it has been possible to further increase the range of physical properties of such material. On forged bars from 3 to 6 inches in diameter engineers are now able to secure a uniform yield point in excess of 70,000 pounds per square inch with an ultimate tensile strength over 90,000 lbs. per sq. in.

T. K. C.

Unique Explosion. (*Chem. & Ind.*, *51*, 291.) Many of us would have enjoyed being with a party of the Fellows of the Chemical Society when guests at the Ardeer Factory of Nobel's Explosives Co., Ltd. An interesting and instructive trip was topped by a demonstration of how spectacularly effective a certain amount of chemical energy can be. A large cast-iron pot 7 ft. diameter by 7 ft. high, and 2–3 in. thick was broken up by means of a charge of explosive. The pot contained about 5 tons of water, and within was suspended a relatively small charge of explosive, 1½ lb. of gelignite. The force of the explosion transmitted by the water to the sides of the vessel resulted in the breaking of the metal into fairly small pieces all of which lay within a radius of a few yards. At the same time, the water was projected into a column about 100 ft. high.

T. K. C.

Food Cooked in Aluminum. (*Ind. & Eng. Chem.*, *24*, 405.) Although aluminum cooking vessels have been used unhesitatingly by preparers of food for several years past, occasional attempts are still being made to scare persons from the use of such metal. Even though actual experience has given us a feeling of safety regarding aluminum, it is reassuring to learn now and then of some well-controlled and purposeful investigation that serves to banish the last traces of doubt.

Workers at the Mellon Institute of Industrial Research have recently completed a study on the aluminum content of foodstuffs cooked in glass and in aluminum. By analysing these cooked foods for aluminum, they could readily determine by difference that proportion of the aluminum content acquired from the cooking utensil of the same material. The investigators have found that clean aluminum utensils are attacked to an insignificant degree by foods of neutral reaction. Acid foods or foods to which baking soda has been added dissolve small amounts of aluminum from utensils. Dark-stained vessels give up more aluminum than those kept bright. The presence of sugar decreases the tendency of the aluminum to dissolve. The greatest quantity of aluminum was found to have been taken up by apple butter cooked in the vessel for 6½ hours. Even then, the quantity was less than one-tenth the amount necessary to exert an influence upon phosphorus assimilation by the body.

T. K. C.

Gasoline from Fish Oil. (FARAGHER, EGLOFF AND MORRELL, *Ind. & Eng. Chem.*, *24*, 440.) A 42-gallon barrel of Menhaden fish oil was cracked at pressures of 60 and 100 pounds per square inch

gauge and operated to produce motor fuel, Diesel oil, coke and gas. The gasoline yields were 37.5 to 47.5 per cent. of the Menhaden oil. After undergoing the usual caustic soda and sulfuric acid treatments, knock-rating values were determined. These were found to have an octane rating of zero due probably to the presence of organic oxygen compounds not removed by the routine treating methods. A special treatment with strong alkali raised the octane number from zero to thirty-one.

The Diesel oil fraction varied from 17 to 36 per cent. of the original oil depending upon the cracking pressures. The gasoline is reported to have a slightly fishy odor and it is not known if an automobile using the same will smell like a planked shad.

T. K. C.

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